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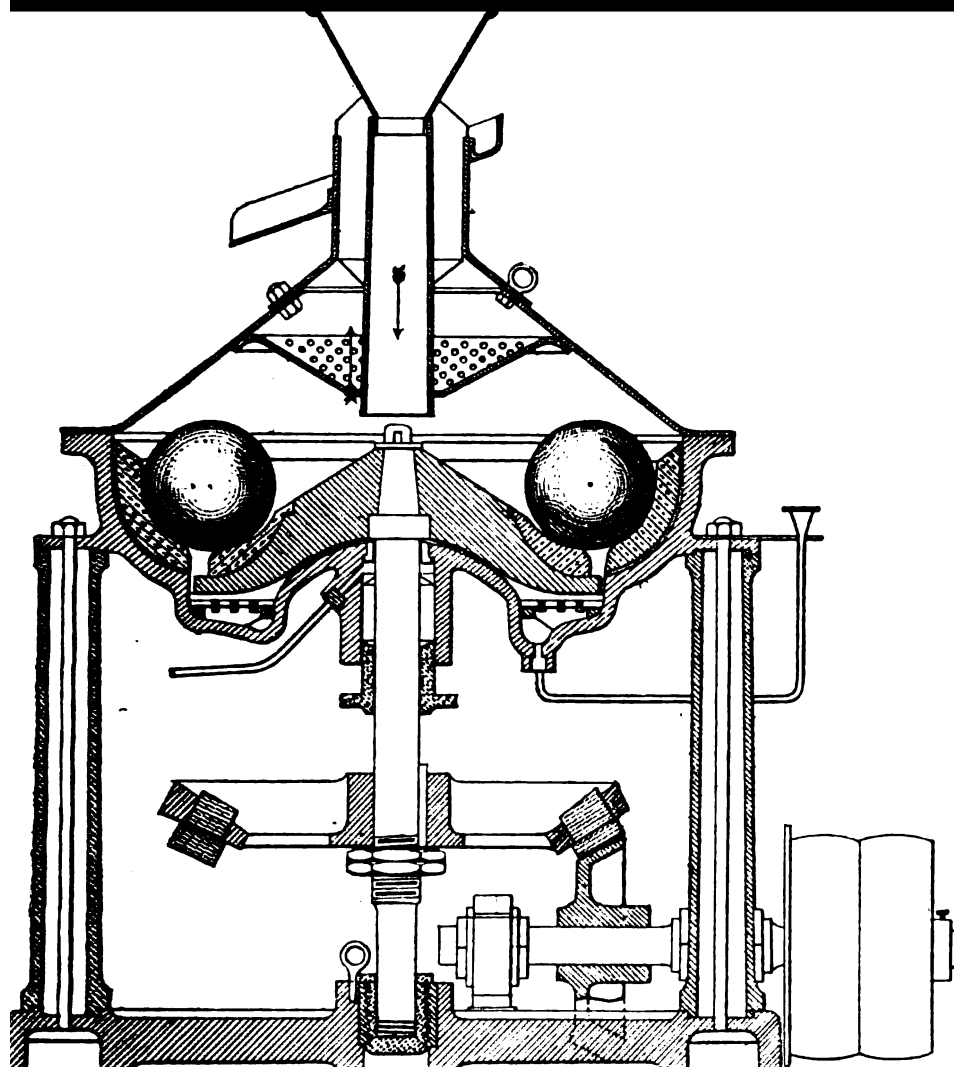
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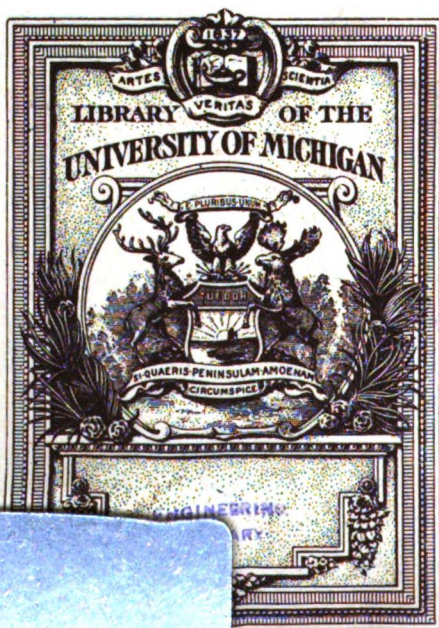


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VIEW OF THE BISHOP ROCK LIGHTHOUSE DURING A NORTH-WEST GALE.

Min. of Proc. Inst. C.E., Vol. cviii.

MINUTES OF PROCEEDINGS

OF

40326

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CVIII.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., SECRETARY.

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CORRIGENDA.

Vol. cvii., pp. 132-170, discussion on Portland Cement. The pages giving references to the Papers have been inadvertently allowed to remain unaltered from the pamphlet edition of this article. The correct paging can be found by adding 28 to the figures given; thus, at p. 132, line 20, for "p. 63," read "p. 91," and so on.

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1891-92.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

12 January, 1892.

GEORGE BERKLEY, President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

ERNEST COLLINS.
EDMOND RICH GABBETT.
WILLIAM PRIOR HALES.
HENRY GEORGE HUMBY.
VITALE DOMENICO DE MICHELE.

LEWIS PRICHARD MOLINE.
CHARLIE KILNER SHEARD.
CHARLES LOUIS SIM.
HENRY MICHELL WHITLEY.

Also that the following Candidates had been admitted as

Students.

HENRY CHARLES ADAMS.
ASHLEY JOHNSTONE BARNETT.
HUBERT CECIL BOOTH.
THOMAS HUGH BULKLEY.
GEORGE HENRY CARMICHAEL.
FREDERICK REILY COLLINS.
BASIL DEVENISH-MEARES, B.E.
ALFRED EDWARDS DOUGLASS.
ERNEST HARRY DRUCE.
JOHN DEVONALD FLETCHER.
JOSEPH GARFIELD.
ALEXANDER GIBB.
THOMAS STEPHEN GILBERT, B.A.
ROBERT THOMAS GREER.
CHARLES LEOPOLD TROYTE GRIFFITH.
REGINALD WILLIAM EUSTACE HAW-
THORN.
GERALD LESLIE LAWRENCE.
ABRAHAM VICTOR LEVI.

ARTHUR ERNEST MALPAS.
JAMES WHITTAKER MARSDEN.
ALEXANDER MILLAR.
HAROLD MUGLISTON.
KENNETH RAMSAY PEARSON.
NEIL JAMES PETERS.
GEORGE ARTHUR PICKEN.
ALEXANDER GORDON ROBERTSON.
JOHN WILSON STEVEN.
GREY HUGH MORVILLE STREATFIELD.
HAROLD ASHETON TONGE.
WILLIAM BEATTIE VENTERS.
JAMES WARRY VICKERS.
ARTHUR WATSON.
ARTHUR EDWARD WILLIAMS, B.A.
CHARLES WALKER WILSON.
GEORGE CROFT ORWIN WOOD.
HENRY MILLS WOOD.

[THE INST. C.E. VOL. CVIII.]

B

The following Candidates were balloted for and duly elected as

Associate-Members.

ARCHIBALD MILES ANDERSON.	ERNEST WORTHY HORNE, Stud. Inst. C.E.
ALFRED HENRY ASLETT, Stud. Inst. C.E.	HERBERT INNES JACQUES, Stud. Inst. C.E.
SIGVARD JOHNSON BERG.	ARTHUR EDWARD KINDERSLEY.
JOHN COWELL STARK BEYNON.	HERBERT CLARK LEWIS.
ISAAC CARR.	FRANCIS JOHN LYNAM, B.E.
CHARLES BASTOW CASEBOURNE.	WALTER SAUNDERS PATERSON.
WILLIAM HENRY COLE.	HENRY CHARLES PLATTS.
WILLIAM CROZIER, JUN.	DAVID THOMAS RHYS PROTHEROE.
BERTHAM WILLIAM ENGLISH, Stud. Inst. C.E.	WILLIAM WADE FITZHERBERT PULLEN, Wh.Sc., Stud. Inst. C.E.
JOHN BERRIDGE GASKELL.	JAMES ROBINSON.
THOMAS GOULDEN.	THOMAS RICHARD SAXTON.
HENRY HOLMES GRAY, Stud. Inst. C.E.	WILLIAM JOHN SHELDON, JUN.
PERCY GRIFFITH.	RICHARD SHOLTO STRACHEY.
JOHN FREDRICK HARRISON, Stud. Inst. C.E.	CHARLES CAMPBELL WARDROP.
FRANCIS GEORGE HARVEY.	JOHN WORMALD.
HENRY JAMES SHEDLOCK HEATHER, B.A.	HENRY WRIXON.
ALFRED HOLDEN.	EDWARD HERBERT YOUNG.

An Associate.

BOVERTON REDWOOD.

MR. BERKLEY, President, said, before calling upon the Secretary to read the Paper of the evening, he desired to express great regret at the loss the Institution, and science generally, had sustained by the death of one of its most eminent Honorary Members—he referred to Sir George Biddell Airy, K.C.B., formerly Astronomer Royal.

(Paper No. 2574.)

“On Weighing-Machines.”

By WILFRID AIRY, M. Inst. C.E.

THE weighing-machines here dealt with are those which are commonly used for trade purposes in England, the typical varieties of which are described and illustrated. The general principles of weighing-machines have been investigated and described by many writers, but the details of them, so far as the Author is aware, have been dealt with by none. It is in connection with the details that the most important practical problems arise, and

with the view of meeting in some degree this want the present Paper has been written. It would have been very difficult for him to have collected the necessary information, and to have made the necessary experiments, without the co-operation of the Standards Department of the Board of Trade, and he desires to acknowledge most heartily the cordial assistance he has received from Mr. H. J. Chaney, the Superintendent of Weights and Measures. He is also indebted to the principal manufacturers of weighing-machines for much courtesy received from them.

All weighing-machines belong to one or other of the following types :—¹

A. Equal-armed Balances—which may be subdivided into—

- (1) Scale-Beams—or Balances in which the scale-pans are *below* the beam.
- (2) Counter Machines—and Balances on the same principle, in which the scale-pans are *above* the beam.

B. Unequal-armed balances—which may be subdivided into—

- (1) Balances consisting of a single steelyard.
- (2) Balances formed by combinations of unequal-armed levers and steelyards, such as Platform Machines, Weighbridges, &c.

C. Spring-Balances.

A. 1. SCALE-BEAMS—OR BALANCES IN WHICH THE SCALE-PANS ARE BELOW THE BEAM.

These are the most accurate weighing-machines. There is no friction except that of the knife-edges, which is extremely small, and there is no multiplication of the power as in the case of steelyards. They are made of all sizes and of all degrees of finish and delicacy, from the tiny balances used by diamond merchants, assayers, and apothecaries, which turn with the $\frac{1}{1000}$ part of a grain, to balances with arms 3 feet long capable of weighing a ton at a time. A first-class bullion balance with 1,000 oz. Troy in each scale-pan will

¹ The trade terms for weighing-machines vary in different parts of the kingdom, and are very loosely applied. Thus, for instance, some kinds of scale beams are frequently termed "Counter Machines." Throughout the present Paper the term "Counter Machines" will be restricted to equal-armed balances in which the scale-pans are above the beam.

turn with half-a-grain, corresponding to nearly the one-millionth part of the load weighed. They are used for standard balances, inspector's balances, and for a multitude of trade purposes, in which they are distinguished as "stand scale-beams" or "suspension scale-beams," according as they are mounted on a stand or hung from some fixed object. They are used exclusively or nearly so by bankers, jewellers, and dealers in precious stones, money and bullion, by silk merchants, assayers, chemists, and apothecaries, and for all purposes where great accuracy is required, and they are used in common with counter-machines in which the scale-pans are above the beam, by butchers and provision dealers, buttermen, grocers and tea-dealers, greengrocers, ironmongers, and tradesmen generally.

Scale-beams of different patterns and with different arrangements are shown in Plate 1, Figs. 1 to 6. The knife-edges are made either of agate or of steel. If made of steel they are hardened to the highest degree possible, and finished with the greatest care and accuracy. Shapes, proportions, &c., of knife-edges will be found on pages 10 to 13. The steel edge is frequently welded into an iron piece to prevent the brittleness and liability of the fulcrum to snap off, which would exist if it were made entirely of hardened steel. The bearings of the knife-edges are of hardened steel or agate, either flat, V-shaped, or cylindrical, and prepared with the greatest possible care. The bearings of the fulcrum knife-edge are either fixed upon a saddle on the top of a stand, or are more commonly carried in a link-shaped piece known as the "gallows," which swings freely from the top of the stand, or from some fixed object. The bearings of the end knife-edges are contained in the suspension links which carry the scale-pans. The pointer attached to the beam is fixed exactly at right angles to the line joining the end knife-edges, and is for the purpose of showing when the beam is horizontal. The indication of the horizontality of the beam is the vertical position of the pointer, as shown when its point exactly coincides with a fixed index in the top of the gallows, or with the zero point on a scale fixed to the stand. The beam is sometimes furnished with a small ball of metal (known as the gravity ball) which can be screwed up or down a stem on the top of the beam for the purpose of accurately adjusting the position of the centre of gravity of the beam. There is frequently a small adjustable weight on a screw projecting horizontally from one end of the beam for the purpose of accurately balancing the arms of the beam.

On the Testing and Adjustment of Scale-Beams.—The conditions

which must be fulfilled by a scale-beam in proper adjustment are as follows :—

- (a) The beam must take up a horizontal position when the weights in the two scale-pans are equal, from nothing to the full weighing capacity of the machine.
- (b) The beam must take up a definite position of equilibrium for a given small difference of weight in the scale-pans. And the sensitiveness, *i.e.*, the angle of deviation of the beam from the horizontal after it has come to rest, due to a given small difference of weight in the scale-pans, should be such as is suited to the purposes for which the balance is intended.

The first condition (a) practically involves three adjustments :—

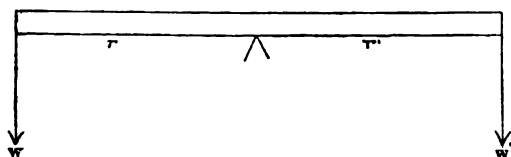
- (1) The empty beam (*i.e.*, the beam without the scale-pans and chains) must be equally balanced and horizontal.
- (2) The two scale-pans with their chains attached must be of equal weight.
- (3) The arms of the beam must be exactly equal in length, *i.e.*, the line joining the end knife-edges must be exactly bisected by a line drawn perpendicular to it from the fulcrum knife-edge. As regards the last of these conditions the beam with the scale-pans attached must be horizontal when the equal weights in the scales are zero, *i.e.*, before any weights are placed in the scales, and this being so the arms must be exactly equal in order that the beam may remain horizontal when any equal weights are placed in the scale-pans, for otherwise the beam would fall over towards the side of the longest arm by reason of the greater leverage on that side. As regards the adjustments (1) and (2), it is true that the beam would weigh correctly, even supposing that the empty beam was out of balance, and the scale-pans with their chains were of unequal weight, provided that these inaccuracies exactly counteracted one another, so that the beam with the scale-pans attached was horizontal. If, for instance, the left-hand arm of the beam were the heavier, and the heavier scale-pan were hung on the knife-edge of the right-hand arm, the balance might be preserved so that the beam was horizontal. But if the scale-pans got interchanged (which is always a possibility) there would obviously be a large error. So that practically the testing and adjustment of a scale beam is carried out as follows :—

First the knife-edges are set out and fixed with the greatest care so that the arms of the beam are as nearly equal as can be ascertained without trial, and the empty beam is adjusted for

balance by filing or by a small weight on a fine screw at one end of the beam till it takes up a perfectly horizontal position. Next, the two scale-pans with their chains attached, after having been made as nearly as possible equal in weight, are hung upon the end knife-edges, and equal standard weights up to the full weighing capacity of the balance are placed in them. Lastly, the simultaneous adjustment of the lengths of the arms and the weights of the scale-pans is effected as follows :—

Let r r' be the lengths of the arms, and W W' the weights of the scale-pans with their chains attached and the equal weights in

Fig. 1.



them. Suppose that the right-hand arm of the beam falls over a little. This may be due to any one of the following causes :—

- (1) r' may be less than r , but W' greater than W . In this case if the scale-pans, &c., be interchanged the beam will fall over to the left more than it did at first to the right.
- (2) r' may be equal to r , but W' greater than W . In this case if the scale-pans, &c., be interchanged the beam will fall over to the left exactly as much as it did at first to the right.
- (3) r' may be greater than r , and W' greater than W . In this case if the scale-pans, &c., be interchanged the beam will fall over either less to the right than it did at first or perhaps absolutely to the left, but not so much to the left as it did at first to the right.
- (4) r' may be greater than r , but W' equal to W . In this case if the scale-pans, &c., be interchanged the beam will remain exactly as it did at first.
- (5) r' may be greater than r , but W' less than W . In this case if the scale-pans, &c., be interchanged the beam will fall over to the right more than it did at first.

It will be noticed that the positions of the beam in the above five cases, after interchanging the scale-pans, &c., follow one

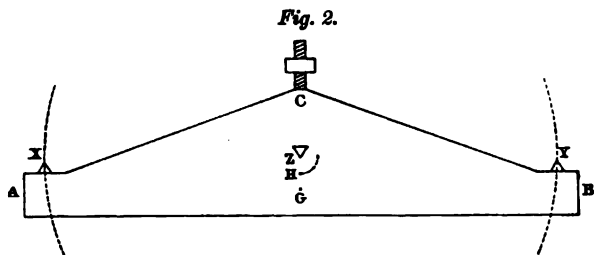
another in sequence; and according to the behaviour of the beam a correct inference can be drawn as to the causes of error. If, as will generally be the case, it is found that there is a very slight difference in the length of the arms, the error must be corrected by working one or other of the end knife-edges with an emery stick so as to throw the edge over in one direction or the other, or by some other delicate method of adjustment. If the correction required is considerable, it will probably throw the empty beam sensibly out of adjustment, and it will have to be readjusted. When the arms are found to be exactly equal, by the indication of case No. 2, then the heavier scale-pan must be reduced by filing to an exact equality with the lighter, as shown by the perfect horizontality of the beam. And the balance is then in adjustment.

With very sensitive balances, considerable skill and patience are required to adjust a balance perfectly, and in general it is considered sufficient to adjust them to such a degree of accuracy that the error is well within the limits allowed. The amount of the errors allowed in different cases will be found on pages 13 and 14, and pages 48 to 51.

The reasons for testing balances with standard weights in the scale-pans, rather than with the scale-pans empty, are (1) because the extreme angles of deviation from the horizontal will be greater with the weights than without them, unless the three knife-edges be exactly in a straight line, and (2) because the balance might be unstable with the weights, though stable without them. This is not an unfrequent occurrence, and arises from the tendency on the part of manufacturers to make balances so extremely sensitive that they are on the verge of instability. This leads up to the second condition (b) of a scale beam in proper adjustment, which is investigated as follows.

On the Conditions of Stability and Sensitiveness of Scale-Beams.—In the diagram below, let A B C be a scale beam, Z the fulcrum knife-edge, and X, Y, the knife-edges on which the scales are hung. It is assumed that the beam is in proper adjustment, and that equal loads are hung at X and Y. Under these circumstances the arms will be of equal length (i.e., the line X Y will be exactly bisected by a perpendicular let fall upon it from Z), the arms will be equally balanced, and the line X Y will be horizontal. Since the forces acting at X and Y are vertical, and will always remain vertical as the beam turns about the point Z, they may be regarded as weights collected at the points X and Y. Let G be the centre of gravity of the empty beam, i.e., of the beam alone, and let H be the centre of gravity of the beam together with the

equal weights supposed collected at the points X and Y. By the assumption, the points G and H will both be in the vertical line through Z. Then, if Z be above H, the balance will obviously be stable, and if a small additional weight (w) is hung at X, the beam will turn about the fulcrum Z until the moment of the weights supposed collected at H about Z exactly balances the moment of (w) about Z. The beam will not at once take up its position of equilibrium, but will sway up and down through that position, and arrive at it by a series of oscillations. The reason for this will be easily seen by describing arcs of circles with centre Z and radii ZX and ZH respectively: if the end A is depressed below the position of equilibrium, the leverage of (w) will be diminished, while that of the weights supposed collected at H will be increased, and if the end A is raised above the position of equilibrium, the leverage of (w) will be increased, while that of the weights collected at H will be diminished. If Z be exactly at H, or below H,



the balance will be unstable, and the smallest additional weight in one of the scale-pans will cause the beam to turn till it is brought up by a stop of some kind. Therefore Z must always be above H. Also, Z must never be so much below the line XY that the beam, when loaded to its full weighing capacity, becomes unstable. The sensitiveness of the balance, i.e., the angle of deviation of the beam from the horizontal due to a very small additional weight (w) will be greater according as the arms of the balance are longer, and the distance ZH is smaller. In general the degree of sensitiveness demanded is extremely great, and the balance is arranged so that Z is almost exactly in the line XY, and an exceedingly small distance above H. The position of G, and consequently of H, can be adjusted to the highest degree of nicety by means of the small weight on the screwed stem at C. The period of an oscillation of the beam will be greater according as the arms are longer and the distance ZH is smaller, and as these are the conditions

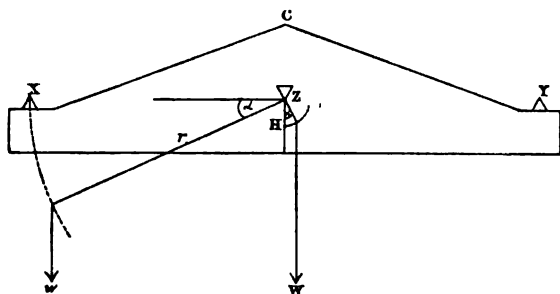
requisite for an extremely sensitive balance, it follows that balances of high sensitiveness are slow to work with.

On the Weighing of very small Quantities.—In balances made for assay and other purposes, requiring the highest degree of delicacy, the following method is adopted for ascertaining very small differences of weight. Suppose that the beam is in perfect adjustment, and let $X Y Z$ be the three knife-edges in the same horizontal straight line. Let H be the centre of gravity of the beam itself, together with the equal loads hung at X and Y , and let W be the sum of the weights supposed collected at H . Let (r) be the length of the arms, and (d) the distance ZH . Let there be a very small additional weight (w) placed in the scale-pan, hung at X , which deflects the beam through the small angle (α) . Then for equilibrium we must have $w \times r \cos \alpha = W \times d \sin \alpha$,

$$\text{or } \tan \alpha = \frac{r}{d} \cdot \frac{w}{W},$$

and therefore $\tan \alpha$ and α vary as $r \times w$. Suppose that the distance

Fig. 3.



XZ or (r) is divided into ten equal parts, and that the top XC of the beam is graduated correspondingly, and that a small weight (a grain, for instance) is hung at any point of the beam. Then it is seen from the formula $\tan \alpha$ varies as $r \times w$, that the small angle of deflection from the horizontal (α) which would be produced by a grain weight hung at the distance $\frac{r}{10}$ (for instance) from the

centre is the same as would be produced by one-tenth of a grain in the scale-pan at the distance r . And therefore by graduating the top of the beam and shifting the rider grain weight till the beam is horizontal, it is easy to ascertain the small difference of weight in the scale-

pans which caused the deflection to the one-hundredth or one-thousandth part of a grain, without using a weight smaller than a grain.

On the Effect of Tilting a Scale-Beam out of Level.—All scale-beams are, or ought to be, provided with a pointer, which, when the stand is level and the beam horizontal, will coincide with a fixed index either on the suspension link, called the "Gallows," or on the stand. If the index be on the gallows, and the gallows be freely hung from the top of the stand, then no error will arise from the stand being out of level, as the gallows will swing vertical. But if the gallows be not free to swing in the direction of the beam, or if the index be attached to the bottom of the stand, then if the stand be tilted in the direction of the beam, it is obvious that the beam will not be horizontal when the pointer coincides with the index, and the effect upon the weighing will be just the same as if the stand had been level, and the goods had been weighed when the pointer did not coincide with the index, and when consequently the beam was not horizontal. With such a balance, if the stand be tilted in the direction of the weights arm of the beam, the apparent weight of the goods will be greater than the real weight, and the balance will be against the purchaser; and if the stand be tilted in the opposite direction, the apparent weight of the goods will be less than the real weight, and the balance will be in favour of the purchaser. The amount of the error (w) for a given angle of tilt (a) can be computed from the equation $w = W \frac{d}{r} \tan a$ (see above), from which it is seen that

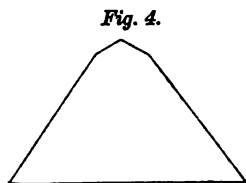
the smaller (d) is the smaller is (w), and the effect of the tilting is less for very sensitive beams than for beams of great stability.

Example.—Suppose that the weight of the beam may be neglected, and that a weight of 4 lbs. is in each scale-pan, so that $W = 8$ lbs. Then the point H (see page 9) is in the line X Y, and for stability the fulcrum Z must be a small distance (d), say $\frac{1}{16}$ inch, above X Y. Let $r = 8$ inches, and $a = 5^\circ$. Then $w = 8 \times \frac{1}{16 \times 8} \times 0.087$ lbs. = 0.087 oz. This example shows that with scale-beams in general a large angle of tilt would be required to produce a large error, because with such balances the distance Z H is almost always very small.

On Knife-Edges.—The preceding investigations and reasoning have taken no account of the friction of the knife-edges. With new and well-constructed machines the friction is extremely small, but it increases with the wear of the knife-edges, and diminishes the sensitiveness of the balances. Very little appears to be known

about the amount of knife-edge friction, or the law of it. The Author has been unable to find any record of systematic experiments on this subject. It is certain that as a knife-edge gets worn and rounded the friction increases, and therefore it would seem that the knife-edge and its bearing reciprocally yield under the pressure, and that the knife-edge turns in its bearing like a journal in a plummer block. While the knife-edge is sharp the journal is small, and the resisting effect of the friction to the motion is small; but as the knife-edge wears rounder the journal becomes larger, and the effect of the friction is greater. But there appears to be no reliable investigation of the subject. The general effect of the friction is to diminish the sensitiveness of a balance, and it is no doubt in consequence of this friction that the makers have been driven to make scale beams which are on the very verge of instability, in order to maintain a very high degree of sensitiveness when the knife-edges are somewhat worn.

No experiments appear to have been made to determine what is the best angle for a knife-edge, according to the conditions under which it is to be used. The knife-edges made by different makers vary extremely in their angles, in fact from about 40° between the sides to 120° , and it is evident that they are designed at random, or by mere rule of thumb. Those made by some of the best makers, and used for the most delicate machines, are as shown in *Fig. 4*, the sides being formed to an angle of about 80° , and the finished edge ground to an angle varying from 110° to 120° .



As regards the length of knife-edge necessary to carry a given load there is no received law. It is invariably the custom to put far less load per inch upon the knife-edges of small machines than upon those of large machines. And for machines of great accuracy the knife-edges are made much longer in proportion to the load than for machines intended for rougher work. In the case of platform machines, and weighbridges, where there is extremely little play of the knife-edges, the loads allowed per inch of knife-edge are very heavy. The following may be taken as the maximum loads in lbs. avoirdupois per inch of acting or efficient knife-edge allowed by the best makers.

- (1.) For scale-beams of the highest accuracy: From $\frac{1}{2}$ lb. per inch for a machine of $\frac{1}{2}$ lb. capacity, to 25 lbs. per inch. for a machine of 80 lbs. capacity.

- (2.) For ordinary trade scale-beams, counter and dead-weight machines: From 20 lbs. per inch for a machine of 7 lbs. capacity, to 600 lbs. per inch for a machine of $\frac{1}{2}$ ton capacity.
- (3.) For platform machines and weighbridges: From 120 lbs. per inch for a machine of 4 cwt. capacity, to 1 ton per inch for a machine of 25 tons capacity.

The above are maximum loads, which, in the case of the larger machines, would rarely come upon them. The average loads for all the machines might probably be taken at one-third of the maximum. In the case of platform machines, &c., it has been assumed that the load is equally divided between the four knife-edges, but, if the load was placed eccentrically, the above maximum might be much exceeded on particular knife-edges. In the case of scale-beams and counter-machines, the above maximum loads will apply to knife-edges and bearings, whether made of agate or of steel, but agate is more brittle than steel, and large balances made with agate knife-edges must be carefully handled to avoid shocks. When balances are to be used in laboratories, chemical works, &c., where acid fumes may be present which would act upon steel, it is essential that the knife-edges and bearings be made of agate.

Bearing in mind the wear of the knife-edges, which causes sluggishness of action, and sensible change of distance between the knife-edges, with the consequent necessity for periodic renewal, the arrangement adopted in Emery's testing-machine is well worthy of consideration. In the levers of this machine there are no knife-edges, but their function is performed by thin steel plates, which are forced under a very heavy pressure into slots formed in the parts that are to be connected, so that the parts are united by the plate. In this case there is no friction, and no sensible wear, so that very great permanency of condition and constancy of action might be expected. But the elastic resistance to bending of the steel plates would be considerable, so that the arrangement is not suitable for scale-beams in which the movement is large. In some respects it would appear to be very suitable for platform machines and weighbridges in which the movement of the lever is very small. But with such machines the load is received upon four or more knife-edges, and it is essential that all the distances between the load knife-edges and the corresponding fulcrum knife-edges should be exactly equal. This condition can be readily secured with ordinary knife-edges, because they can be separately

worked and adjusted, but it does not seem easy to ensure it with the steel plate connections. And it would not always be convenient to have the levers permanently connected together. If these difficulties could be overcome, the Emery system would appear to have great advantages. The Emery machine is described and drawn in the Proceedings of the Institution of Mechanical Engineers for May, 1888.

Amount of "Sensitiveness" Error allowed on Scale-Beams.—Inspectors' scale-beams are usually made in sets of three, and the rules adopted with regard to their sensitiveness are as follows. The smallest balance is for testing weights up to 1 lb. avoirdupois; it has arms about $5\frac{1}{2}$ inches long, and should sensibly turn with at most $2\frac{1}{2}$ grains when $\frac{1}{2}$ lb. is in each scale-pan. The middle-sized balance is for testing weights from 1 lb. to 7 lbs.; it has arms about 8 inches long, and should turn with at most 5 grains when $3\frac{1}{2}$ lbs. are in each scale-pan. The largest balance is for testing weights from 7 lbs. to 56 lbs., it has arms about 15 inches long, and should turn with at most 15 grains when 28 lbs. are in each scale-pan. Most of the balances made for inspectors' use turn with very much less than the quantities mentioned above.

According to the rules of the Board of Trade, scale-beams made for trade purposes are to be divided into three classes, according to the purposes for which they are intended, and should be marked Class I, Class II, or Class III, as the case may be. Those of Class I are the most accurate, and may be stamped by the inspectors if they turn with at most the following amounts:—

If intended to weigh up to 2 cwt.		$\frac{1}{2}$ ounce.
" " 1 "		$\frac{1}{4}$ "
" " 56 lbs.		$\frac{1}{8}$ "
" " 14 "		$\frac{1}{16}$ "
" " 7 "		20 grains.
" " 4 "		5 "
" " 1 lb.		2 "
" " 1 oz.		1 grain.

Scale-beams of Class II are such as those used for weighing bread and meat, and should turn with at most four times the amounts given in the Table above. And scale-beams of Class III are such as those used by itinerant vendors, or for weighing coal, vegetables, wood, and metals, and should turn with at most six times the amounts given in the Table above.

The Board of Trade have not laid down rules for the total errors permissible for scale-beams and other machines, of which the

"sensitiveness" error is only a part. For a discussion of this important subject, see pages 48 to 51.

The principal types of scale-beams in common use are shown in Plate 1, Figs. 1 to 6, and described on pages 53 to 55. The examples are all taken from machines constructed by the best makers, and each type possesses advantages, which will be pointed out as they are severally described.

A. 2. COUNTER MACHINES, AND BALANCES ON THE SAME PRINCIPLE, IN WHICH THE SCALE-PANS ARE ABOVE THE BEAM.

These form a very large and useful class of weighing-machines, and have an advantage over scale-beams, in the scale-pans being unencumbered with suspension chains and the overhead beam. They are usually made with two beams, each with its three knife-edges, rigidly tied together, or cast in one piece, and a considerable distance apart, so that the scale-pans being carried on two knife-edges each are prevented from tipping over sideways. To prevent the scale-pans from tipping over in the direction of the beams a vertical leg is rigidly fastened to the underside of each pan, and is continued downwards below the beams, and its lower end is loosely secured by a horizontal stay to a pin in the middle of the frame. Sometimes the vertical leg is carried upwards instead of downwards, and its upper end is loosely secured by a stay to a pin in a pillar of the frame; with this arrangement the balance is called an "inverted counter machine." Stops are fixed on the vertical legs to limit the range of sway of the beams.

From the above description, it will be seen at once that these balances will not be so accurate as balances in which the scale-pans are freely hung from the ends of the beam. For there is the probability that the two beams will not be of exactly the same length, there will be increased knife-edge friction, and, above all, there will be the friction of the stays, and horizontal forces due to the stays. But they are cheap, and can be made with sufficient accuracy for the great bulk of every-day dealings, and their handiness and compactness render them exceedingly useful. In weighing out goods with these machines, there is seldom any question of determining the exact weight to any great nicety, and rapid action is generally of high importance. Hence these machines are very commonly made unstable, or "accelerating," i.e., they are constructed with the fulcrum knife-edges lower than

the line joining the end knife-edges, and they are arranged so that the beam is horizontal when the stop of the weights pan is hard down on its bearings. This arrangement is well adapted for weighing out parcels of goods of a definite weight. The required weight is placed in the weights pan, and the goods are then filled into the goods pan till the goods pan sinks, and the least weight of goods that will stir the goods pan is the weight of goods required. When the goods pan once moves it will continue to descend with "accelerating" velocity till it is brought up by its stop. And in this way parcels of goods of definite weight are weighed out with tolerable accuracy, and with great rapidity. Machines of this construction are adopted by the Post Office Department for weighing parcels, and are well suited for the purpose, as the object is generally to ascertain whether the weight of the parcel exceeds a certain amount or not. But they are not so well adapted for ascertaining the correct weight of a given article or a given parcel of goods, as will be seen hereafter; and for this purpose machines should be used of which the beams are made stable, or "vibrating," by a proper arrangement of the knife-edges, and such machines are also very common. But the workmanship demanded is rather more delicate, especially in the construction of the stays.

There is not much variation in the construction and arrangement of the stays of counter-machines, and they are commonly made as shown in Plate 1, Figs. 10. But with the view of diminishing the friction, the function of stays have sometimes been performed by an upper beam precisely similar in all respects to the real beam of the machine, and working exactly parallel to it and with it. The legs of the pans take bearing on the end knife-edges of this upper beam, and the small horizontal pull due to eccentric disposition of the loads is met by the rounded or V-shaped bearings of the knife-edges.

Counter-machines are used most extensively by grocers, provision dealers, confectioners, fruiterers, greengrocers, fishmongers, butchers, costermongers, and tradesmen generally. They are used by the Post Office for weighing parcels, and are to be found in most houses for domestic use. They are made of different sizes, and different degrees of delicacy, and are fitted with goods pans of different shapes and sizes according to the trades for which they are intended. They are often made of large size, and are much used for weighing heavy boxes of fish, sacks of flour and vegetables, coal in sacks, scrap iron, and miscellaneous goods up to the weight of 2 cwt., and when of this size, go by the trade term of

"dead-weight machines," as opposed to "platform machines," where the power is multiplied by means of levers.

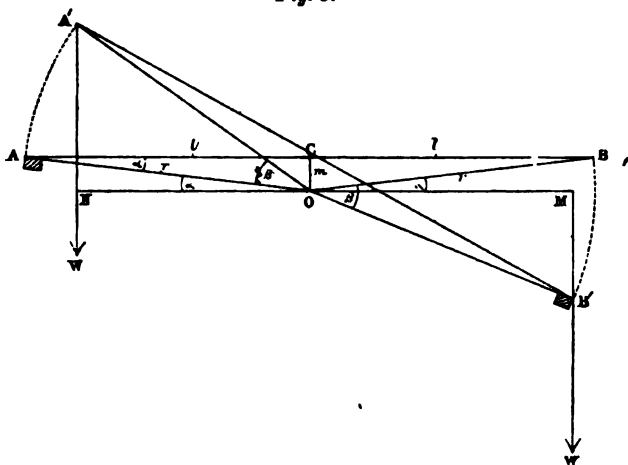
In the construction of accelerating counter-machines care should be taken that they are not made too unstable. Because with unstable balances, although the smallest difference of weight in the scale-pans will cause the heavier one to descend till it is brought up by its stop and to remain there, yet being in this position, a very much greater weight than the difference which brought it there will be required in the opposite scale to enable it to mount again. This is proved in the next article, and it is there shown by an example how such machines can be used to facilitate fraud. Again, these machines are frequently made with broad flat pans to receive the goods to be weighed, and it will generally be found that the apparent weight of the goods will vary according as they are placed on the side of the pan nearest to the fulcrum or on the opposite side. The reason of this is investigated on pages 18 to 21, and it is there shown how this source of error and possible fraud may be removed by careful adjustment of the stays.

To calculate the additional weight required in the weights-pan of an "accelerating" or unstable balance, when loaded with equal weights in the two pans, in order to enable the goods pan to rise.—Let $A O B$, Fig. 5, be the beam in its horizontal position, A being the weights end of the beam hard down on its stop, and B the goods end of the beam, and let O be the fulcrum. The beam will turn about O and the ends A and B will describe arcs of a circle whose centre is O and radius $O A = r$. Let $A' O B'$ be the beam in its displaced position with the goods end B' hard down on its stop, and complete the figure. Let (α) be the angle $O A B = O B A$ which defines the amount of acceleration, and (β) the angle $A O A' = B O B'$ which defines the range of sway of the beam. Then omitting the weight of the beam, and supposing a weight W hung at each end, the moment on the right-hand side, tending to keep the end B' down $= W \times O M = W \times B' O \cos (\beta - \alpha) = W \cdot r \cdot \cos (\beta - \alpha)$, and the moment on the left-hand side, tending to raise the end $B' = W \times O N = W \times A' O \cos (\beta + \alpha) = W \cdot r \cdot \cos (\beta + \alpha)$. The difference of these moments $= W \cdot r \{ \cos (\beta - \alpha) - \cos (\beta + \alpha) \} = W \cdot r \cdot 2 \sin \alpha \sin \beta$. If (w) be the additional weight required at A' in order to raise the end B' , $w \times O N = W \cdot r \cdot 2 \sin \alpha \sin \beta$, or $w \times r \cos (\beta + \alpha) = W \cdot r \cdot 2 \sin \alpha \sin \beta$, or $w = W \frac{2 \tan \alpha \tan \beta}{1 - \tan \alpha \tan \beta}$.

Let $A B = 2 l$ and $O C = m$, then $\tan \alpha = \frac{O C}{A C} = \frac{m}{l}$ and $w = W$.

$\frac{2m \tan \beta}{l - m \tan \beta}$. If the stop at B' be at a vertical distance (d) below A, $d = r \sin \alpha + r \sin (\beta - \alpha)$, and $\frac{d}{r} = \sin \alpha + \sin (\beta - \alpha)$. Now $r = \sqrt{l^2 + m^2}$ and $\sin \alpha = \frac{m}{\sqrt{l^2 + m^2}}$, $\therefore \sin (\beta - \alpha) = \frac{d}{r} - \sin \alpha = \frac{d}{\sqrt{l^2 + m^2}} - \frac{m}{\sqrt{l^2 + m^2}} = \frac{d - m}{\sqrt{l^2 + m^2}}$, and since (m) is always extremely small compared with (l), $\sin (\beta - \alpha) = \frac{d - m}{l}$. From

Fig. 5.



this equation (β) can be determined, and its value substituted in the equation for (w).

Example.—In a certain machine $m = 0.16$ inch, $l = 3.94$ inches, $d = 0.5$ inch, $\therefore \tan \alpha = \frac{m}{l} = \frac{0.16}{3.94} = 0.041$, and $\alpha = 2^\circ 19'$; $\sin (\beta - \alpha) = \frac{d - m}{l} = \frac{0.5 - 0.16}{3.94} = + \frac{0.34}{3.94} = + 0.086 \therefore \beta - \alpha = + 4^\circ 57'$ and $\beta = 4^\circ 57' + 2^\circ 19' = 7^\circ 16'$. $w = W \cdot \frac{2m \tan \beta}{l - m \tan \beta} = W \cdot \frac{2 \times 0.16 \times 0.127}{3.94 - 0.16 \times 0.127} = W \times 0.0104$. If $W = 4$ lbs. = 64 oz., $w = 64 \times 0.0104 = 0.6656$ oz., or two-thirds of an ounce.

If therefore with this machine a grocer were to place a 4-lb. weight in the weights-pan, and were then to fill goods into the

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goods-pan till it dropped, and were then to abstract from it a portion of what he had filled in till the goods-pan rose again, the customer would be defrauded to the extent of $\frac{2}{3}$ oz. Again if, as is commonly done, a fishmonger were to use such a machine to ascertain the weight of a piece of fish, which he places in the goods scale-pan and thereby depresses the pan down upon its bearings, and then places weights in the weights-pan till the goods-pan rises, the customer is defrauded to the extent of $\frac{2}{3}$ oz. for every 4 lbs. weighed. Even when the errors due to the construction of the machine are not so large as those in the example above given, it is in the power of a vendor to use the machine to his advantage; because in many transactions it is not usual to weigh closer than to 1 oz., and the mere turn of the scale would be taken as equivalent to an additional oz., which would always be claimed by the vendor.

Investigation of the effect of placing the load eccentrically on the pan of a Counter Machine.—In this investigation it will be assumed that the line AB joining the end knife-edges is horizontal. Let C be the fulcrum knife-edge— C may be either above or below AB —in general it is a very small distance below AB , as in the diagram. Let DE be the goods-pan, hanging on the knife-edge at A , and prevented from tipping over in the direction of the beam by the stay KG , which is inclined to the horizontal at an angle θ , and turns about a fixed pin at K . The point G is in the vertical leg which is attached rigidly to the middle of the pan and passes behind the beam in the diagram; the stay KG is loosely attached at G so as in no way to hinder the up and down movement of the pan, which does not usually exceed $\frac{1}{2}$ inch. Let there be a weight W in each pan, that in the pan for weights being always placed vertically over the knife-edge, and that in the goods-pan at a distance (a) from the knife-edge. Let (h) be the vertical distance of G from the knife-edge at A , (l) the distance AC , and (m) the small vertical distance of the line AB from C . The quantities (a), (m), and (θ) will be considered +^u when they are as shown in the figure. That is to say, (a) will be considered +^u when the weight is placed to the right of F , (m) will be considered +^u when AB is above C , and (θ) will be considered +^u when the stay KG is above the horizontal through G . And they will severally be considered -^u when in the opposite directions.

Let the state of things be as in *Fig. 6*. Then for the equilibrium of the pan DE and its attached parts there must be a thrust force H communicated by the stay KG to G such as will balance the moment $W \times a$. The force H is equivalent to a

horizontal force $H \cos \theta$, and a vertical force $H \sin \theta$. Equating moments about the point A we get $H \cos \theta \times h = W \times a$, or

$H = W \cdot \frac{a}{h \cos \theta}$. Therefore the force H is equivalent to a horizontal

force $= W \cdot \frac{a}{h}$, and a vertical force $W \cdot \frac{a}{h} \cdot \tan \theta$. The horizontal force

$W \cdot \frac{a}{h}$ is transmitted to the knife-edge A, and acts in the direction

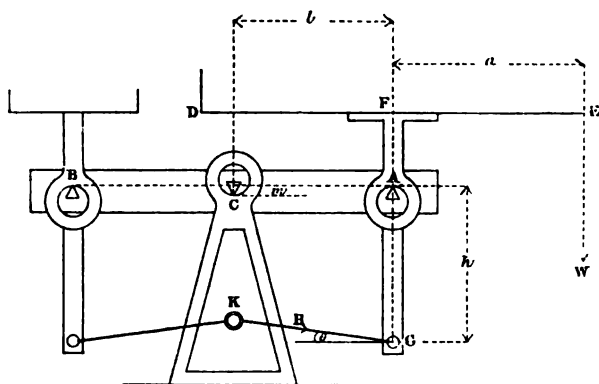
BA, tending to tilt the end A of the beam downwards with a

moment $W \cdot \frac{a}{h} \cdot m$. This moment is equivalent to a little addition of

weight (p) in the pan DE at F. Therefore (p) is $+$ and $p \times l$

$= W \cdot \frac{a}{h} \cdot m$, or $p = + W \cdot \frac{a}{h} \cdot \frac{m}{l}$. The vertical force $W \cdot \frac{a}{h} \tan \theta$ also

Fig. 6.



acts downwards, and is equivalent to an addition of weight at F of that amount. So that the effect of placing the weight W at E instead of F is to cause the end of the beam to descend, as if under the action of an additional load (w) at F such that $w = W \cdot \frac{a}{h} \cdot \tan \theta$.

$+ W \cdot \frac{a}{h}$. If the weight W had been placed to the left of F the same reasoning will show that the force H would have been a pull force instead of a thrust force, and that the effect of the horizontal component of H would have been to tilt the end A of the beam upwards, and the vertical component of H would also have been an upward force. So that the total effect would have been an apparent diminution of the load in the pan.

The above equation for the value of (w) will apply to all cases by giving their proper signs to the different quantities. And the condition that must exist in order that the balance may weigh correctly for all positions of the weight W is evidently $w = 0$, or

$$W \cdot \frac{a}{h} \cdot \frac{m}{l} + W \cdot \frac{a}{h} \cdot \tan \theta = 0, \text{ or } \tan \theta = - \frac{m}{l}.$$

This is equivalent to saying that the stay KG must be parallel to the line joining the points A and C , and the adjustment must be effected either by raising or lowering the pin K , or by lowering or raising the point of attachment of the stay at G , as the case may require.

From the equation for (w) it is seen that the larger (h) is the smaller (w) will be. Therefore for the larger counter machines, where it is not convenient to have the scale pans raised high above the counter, and for "dead-weight machines" on the same principle, where it is not convenient to have the scale-pans raised high above the floor, there is an advantage in adopting the "inverted counter-machine" arrangement (see Plate 1, Figs. 9), because the vertical leg can be produced upwards as high as is required, and this arrangement is very common.

Example.—In a certain counter machine it was found by trial that with $W = 4$ lbs. = 64 ozs., and $a = + 1.75$ inch, (w) was $+ 0.36$ oz. The other quantities were $h = 4.375$ inches, $l = 4.03$ inches, $m = + 0.031$ inch. Then the equation gives

$$\begin{aligned} 64 \times \frac{1.75}{4.375} \times \frac{0.031}{4.03} + 64 \times \frac{1.75}{4.375} \times \tan \theta &= + 0.36, \\ 0.197 + 25.6 \tan \theta &= + 0.36, \\ \tan \theta &= 0.0063. \end{aligned}$$

Let (x) be the vertical distance of the pin K from the horizontal through G , corresponding to the angle θ . Then $\tan \theta = \frac{x}{l}$, or $x = l \tan \theta = 4.03 \times 0.0063 = 0.025$ in. The condition for adjustment requires that $\tan \theta = - \frac{m}{l}$, or $x = -m = -0.031$ inch. Therefore, for the necessary adjustment the pin K must be lowered $0.025 + 0.031 = 0.056$ inch, or the pin at G raised 0.056 inch. Until the adjustment is effected it would be in the power of the vendor, by always placing the goods on the edge of the pan furthest from the fulcrum, to defraud the customers to the extent of 0.36 oz., or more than $\frac{1}{3}$ oz. for every 4 lbs. weighed. Similarly if the stay of the

weights pan were not in correct adjustment it would be possible to do something in the way of fraud by placing the weights on the edge of the pan instead of in the middle, though not so efficiently as in the goods pan by reason of the smaller size of the weights pan.

Effect of placing a counter-machine out of level on the apparent weight of the goods weighed.—This is a matter of importance, because these machines are very largely used by costermongers and itinerant vendors, whose barrows are rarely level, and are commonly very much tilted. There are different cases according as the machine is “accelerating” or “vibrating,” and according as it is tilted one way or the other, but they are all embraced under one formula as follows:—

Neglecting the weight of the beam, let $A O B$ be the beam of an accelerating machine, A being the weights end knife-edge and B the goods end knife-edge. The beam is limited in its sway by the stops at the points A and B' , and the machine is so constructed that when it is placed on a level table, and the weights end A of the beam is hard down upon its stop, the line $A B$ joining the end knife-edges is horizontal. Let $A O B$ be the position of the beam when the machine is tilted at an angle (θ) to the horizontal, and let O be the fulcrum. The beam will turn about the point O , and the points A and B will describe arcs of a circle whose radius is r . Let (β) be the angle which measures the limiting sway of the beam as defined by the stops, and let (α) be the angle which defines the degree of acceleration of the beam as depending upon the positions of the knife-edges. Suppose now that equal weights W are placed in the pans at A and B , and let the beam be displaced into the position $A' O B'$. Then, in the same manner as on page 16, it may be shown that the additional weight (w) which is needed at A' to make the end B' rise off its stop is determined by the equation

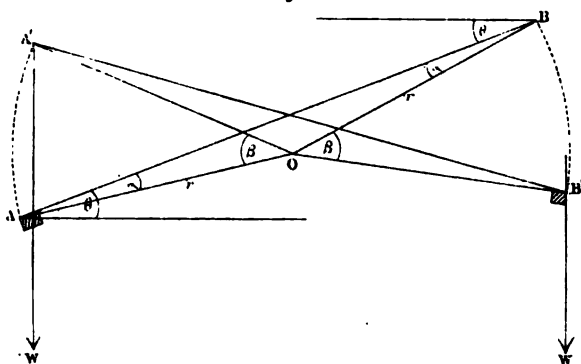
$$w = W \frac{2 \tan (\beta - \theta) \cdot \tan \alpha}{1 - \tan (\beta - \theta) \cdot \tan \alpha}.$$

This is the general formula from which can be deduced the effect of tilting counter-machines, either accelerating or vibrating, in either direction.

First.—Let the machine be an accelerating machine, as in the diagram. Then (α) is $+$, and $\tan \alpha$ is $+$; (α) is a very small angle, and the denominator of the fraction will always be $+$. If the machine be tilted as in the diagram (θ) is $+$, and if in the opposite direction (θ) is $-$. If (θ) be $+$ and larger than (β) , (w) is

$-''$, and the beam has a natural tendency to change its position from $A'O B'$ to $A O B$, so that for equilibrium a small weight must be placed in the goods pan. In this case the apparent weight of the goods is less than the real weight, and the machine is in favour of the purchaser. If (θ) be $+''$ and equal to (β) , $w = 0$, and the machine weighs correctly. If (θ) be $+''$ and less than (β) , (w) is $+''$, and a small weight is needed in the weights pan to make the goods pan rise from its stop; in this case the apparent weight of the goods is greater than the real weight, and the machine is against the purchaser. As (θ) diminishes, still remaining $+''$, the machine acts more and more against the purchaser, and when $\theta = 0$, i.e., when the machine is level, the condition of things is as was investigated on pages 16 and 17. If (θ) is $-''$, i.e., if the machine is tilted in the opposite direction, (w) is still $+''$, and

Fig. 7.



continues to increase positively as (θ) increases negatively, so that when the machine is tilted in this direction it always acts against the purchaser, and the more so the more it is tilted.

Secondly.—Let the machine be vibrating. Then (α) and $\tan \alpha$ are $-''$, and the sign of (w) will always be the reverse of what it was for an accelerating machine, and the changes of (w) for different values of (θ) can be followed as before. But in the case of vibrating machines the three knife-edges are always so nearly in the same straight line that (α) is very small, and consequently the values of (w) are always very small; and for the purposes for which they are used, vibrating machines will in general weigh pretty correctly however much they are tilted.

If an accelerating machine have a considerable degree of acceleration, and be considerably tilted (as they frequently are), the

value of (w) against the purchaser will be considerable for a large — value of (θ). For example, let $W = 4 \text{ lbs.} = 64 \text{ ozs.}$, $\alpha = 2^\circ 19'$, $\beta = 7^\circ 16'$; all as in the example on page 17. Then if $\theta = -9^\circ 36'$, which is the angle due to a tilt of 2 inches on a machine 12 inches long,

$$w = 64 \times \frac{2 \tan (7^\circ 16' + 9^\circ 36') \cdot \tan 2^\circ 19'}{1 - \tan (7^\circ 16' + 9^\circ 36') \cdot \tan 2^\circ 19'} = 1.6 \text{ oz.}$$

which is exactly the result that was found by direct trial with the machine. The value of (w) when the machine was set level was, as computed on page 17, and confirmed by direct experiment, 0.66 oz. So that the effect of the tilting is to increase the amount by which it acts against the purchaser to the extent of about 1 oz.

If an accelerating counter-machine be used, as is done at Post Offices, to ascertain whether or no a parcel exceeds a certain weight, the effect of the machine being out of level on the apparent weight of the parcel is found thus:—Put $\beta = 0$ in the formula $w = W \frac{2 \tan (\beta - \theta) \tan \alpha}{1 - \tan (\beta - \theta) \tan \alpha}$, then $w = -W \frac{2 \tan \theta \tan \alpha}{1 + \tan \theta \tan \alpha}$. If (θ) is +°, (w) is —°, and the machine is in favour of the public. If (θ) is —°, (w) is +°, and the machine when so tilted is against the public.

Amount of "Sensitiveness" Error allowed on Counter-Machines.—According to the rules of the Board of Trade, counter-machines made for trade purposes are to be divided into three classes, according to the purposes for which they are intended, and should be marked Class I, Class II, or Class III, as the case may be. Those of Class I are the most accurate, and may be stamped by the inspectors if they turn with at most the following amounts:—

If intended to weigh up to 2 cwt.	1 ounce.
" " 1 "	$\frac{1}{2}$ "
" " 56 lbs.	$\frac{1}{4}$ "
" " 14 "	$\frac{1}{8}$ "
" " 7 "	$\frac{1}{16}$ "
" " 4 "	20 grains.
" " 1 lb.	10 "
" " 1 oz.	5 "

Counter-machines of Class II are such as those used for weighing bread and meat, and should turn with at most four times the amounts given in the Table above. And counter-machines of Class III are such as those used by itinerant vendors, or for weighing coal, vegetables, wood, and metals, and should turn with at most six times the amounts given in the Table above. For a

discussion of the subject of the sensitiveness and other errors of trade balances, see pages 48 to 51.

Examples of the ordinary types of counter-machines are shown in Plate 1, Figs. 7 to 9, and described on pages 55 and 56.

B 1. BALANCES CONSISTING OF A SINGLE STEELYARD.

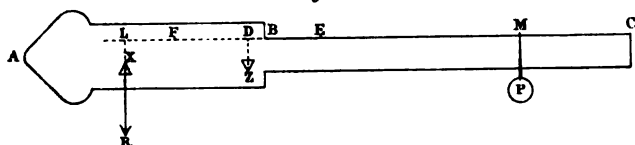
These also form a very large class of weighing machines. They are simple, reliable, and durable. The weights to be handled are smaller than in the case of scale-beams, by reason of the greater leverage which they exert, and the pressure on the fulcrum knife-edge is less. Steelyards can therefore be made lighter and cheaper than scale-beams to do the same work. They are not in general so accurate as equal-armed balances for the following reasons:—First, because a small weight on the long arm of the steelyard balances a heavy load on the short arm, and therefore a very small error in one of the steelyard weights causes a sensible error in the apparent weight of the goods weighed. Secondly, because an extremely small error or change in the distance between the fulcrum knife-edge and the load knife-edge makes a sensible error in the apparent weight of the goods weighed; and thirdly, because a large increase of load requires but a small movement of the sliding poise to balance it; and unless special contrivances are introduced in order to read the position of the poise with very great accuracy, there will be a little uncertainty as to the reading. In general no attempt is made to weigh to very great accuracy with these machines: the steelyard is nicked with divisions corresponding to 1 oz., 4 ozs., 1 lb., &c., according to the purposes for which the machine is intended, and it would generally be possible to estimate the weight of the load to one-half of these quantities. But when carefully nicked they are very accurate, as also well adapted for weighing out definite quantities of goods, such as $\frac{1}{2}$ lb., 1 lb., 2 lbs., &c., as in such cases there would be no question of estimation. These balances are used for weighing trusses of straw and hay, bags of hair and rags, small coal at the pit's mouth, and a great variety of materials. They are also used for testing-machines, personal weighing-machines, and general shop purposes. But when used for trade, they are not commonly made to weigh more than 2 cwt. at a time. For loads exceeding 2 cwt., platform-machines involving combinations of unequal-armed levers are generally used, as in these the power is multiplied to a far greater extent than by simple steelyards.

The theory of the steelyard, and the chief problems connected with the use of it according as it is made—"accelerating" or "vibrating"—will now be dealt with.

Theory and Arrangement of the Common Steelyard.—The most generally convenient way of using a steelyard to weigh a load is to bring it into a horizontal position by means of movable weights, and to infer the amount of the load from the positions of the movable weights, in accordance with the law that follows. This is the method almost universally adopted. But it is not the only method, and for special purposes it is sometimes convenient to use a fixed weight on the long arm of the steelyard, and to infer the amount of the load from the position of the steelyard, as in the examples given on pages 26 to 28.

Let ABC be the steelyard in a horizontal position, Z the fulcrum, X the knife-edge on which the load R is hung, and BC the portion of the steelyard on which the sliding poise P travels. Produce the line CB, and let the perpendiculars from Z and X upon CB meet it in the points D and L. The steelyard without

Fig. 8.



any load hanging at X has commonly a tendency to overbalance on the side of the long arm. Let this tendency be measured by the moment produced by the sliding poise when hanging at the point E, and make $DF = DE$. Then if M be the position of P when the load R is hung at X, and the steelyard is in equilibrium, we have $R \times LD = P \times DE + P \times DM = P \times FM$; $\therefore FM = \frac{R}{P}$

$\times LD$. Therefore the distance FM is proportional to the load hung at X, and the steelyard can be graduated for all values of R within the range of P.

This is the simple theory of the steelyard, and the commoner kinds of steelyards are constructed accordingly. The more accurate and elaborate steelyards are made either with a heavy travelling poise to measure the bulk of the load, and a light travelling poise to measure the remainder, or else with a knife-edge at the end of the steelyard on which loose weights are hung to measure the bulk of the load, and a light travelling poise to

measure the remainder. The advantage of the first arrangement is that the weights on the steelyard are always the same, and there will be no inconsistencies of indication. The advantage of the second arrangement is that the sum of the loose weights hung at the end of the steelyard required to balance the load is much less than the weight of the large travelling poise in the first arrangement, and therefore the load on the fulcrum is less, and there is less weight to be moved. The disadvantage of it is that unless the loose weights to be hung at the end of the steelyard are extremely accurate and consistent among themselves, the error would be considerable by reason of the great leverage they exert. Both these arrangements are in common use.

It has already been said that one of the causes of error in using steelyards is the difficulty of reading the position of the sliding poise to a great degree of accuracy. The following arrangement has been devised to meet this difficulty. The single heavy poise is carried along the steelyard by a short rigid bar attached rigidly at its other end to a block which runs on a screwed rod. This rod is below the steelyard and parallel to it, and in fact forms a portion of the steelyard. A graduated disk wheel with a handle is fixed to the end of the screwed rod, and the thread of the screw is made such that a complete turn of the handle draws the poise along the steelyard exactly one whole division on the steelyard. For any intermediate position, the uppermost figure on the disk wheel will show correctly the proportionate part of a division.

Examples of Steelyards without movable weights. Example I.—Suppose that ABC, Fig. 9, is a thick disk capable of turning on an axis at O. Let R be the load, applied by means of a cord wrapped round the edge of the disk and attached to it, so that as the disk turns the leverage of R is always the same. Let W be a weight rigidly attached to the disk by a bar, so that its leverage about O varies as the disk is turned. Suppose that the disk is in equilibrium when the angle BOC which the rigid bar makes with the horizontal is (θ) , and let the radius AO of the disk be (r) , and the distance of the centre of gravity of the weight from O be (l) . Then $R \times r = W \times l \cos \theta$, which gives the position of the weight for the load R. And if by a simple mechanical arrangement the disk be made to actuate an index finger on a dial, and the dial be graduated to show the correct loads due to the different positions of W, then the amount of the load can be read off the dial plate. This is the principle of the automatic weighing-machine, which is further described on page 58 and shown in Plate 2, Fig. 4. Although for convenience the disk is introduced, it will be seen

that the arrangement is simply that of a steelyard with a fixed weight and a varying leverage proportion.

Example II.—Let AB, *Fig. 10*, be a steelyard whose fulcrum is C, and (*a*) and (*b*) the lengths of the short and long arms. From the end of the long arm at B is hung a heavy cylinder immersed in a

Fig. 9.

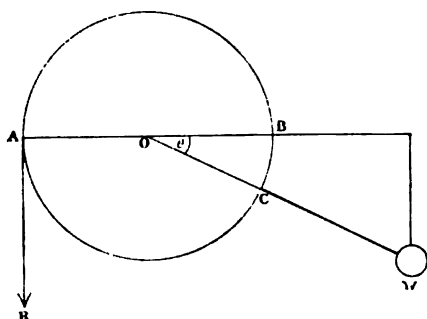
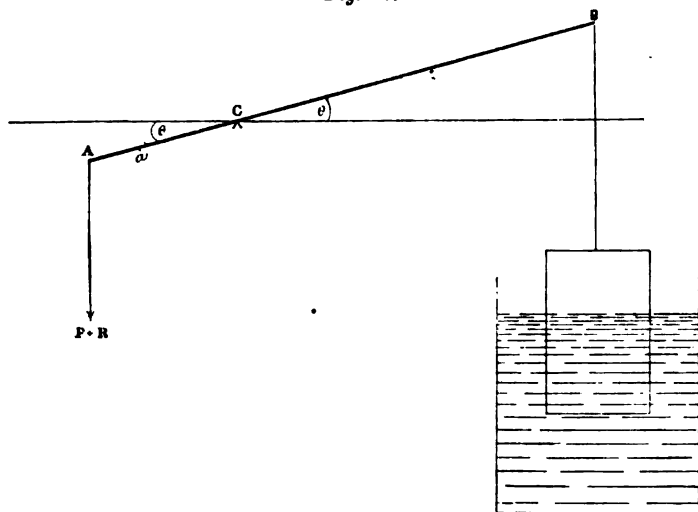


Fig. 10.



cistern of water. Suppose that when the steelyard is horizontal the cylinder is immersed to a depth (*d*) in the water, and that the weight (*P*) of the platform and gearing just balances the cylinder. Let (*r*) be the radius of the cylinder, (*γ*) the weight of a cubic foot of water, and (*W*) the weight of the cylinder in air. Then $P \times a = (W - \pi r^2 \cdot d \cdot \gamma) \times b$. If now a weight *R* be placed on

the platform, and the cylinder in consequence be drawn a height (x) out of the water, and the steelyard be inclined at an angle (θ) to the horizontal,

$$(P + R) \times a \cos \theta = \{W - \pi r^2 (d - x) \gamma\} \times b \cos \theta,$$

$$\text{or } (P + R) \times a = \{W - \pi r^2 (d - x) \gamma\} \times b,$$

$$\therefore R \times a = \pi r^2 \gamma \cdot x \cdot b,$$

$$\therefore x = R \frac{a}{b} \frac{1}{\pi r^2 \gamma} \text{ and } (x) \text{ varies as } R.$$

If therefore a cord be attached to the end of the long arm, and be made to actuate the index finger of a graduated dial or quadrant, the weight on the platform can be read off by inspection. This is the principle of some convenient machines used for weighing out coal at the pit's mouth, &c., and for purposes where great accuracy is not required. In this example the leverage proportion is constant, but the weight on the end of the long arm varies with the position of the steelyard.

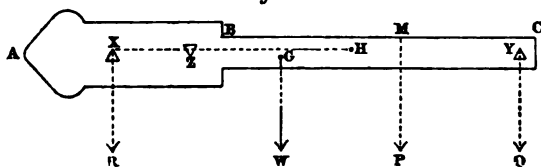
On the conditions necessary for a Steelyard to be "accelerating" or "vibrating."—In this investigation it will be assumed that the bulk of the power is applied by means of loose weights hung on a knife-edge at the end of the steelyard, but the reasoning will apply equally to the case where the bulk of the power is applied by means of a heavy travelling poise.

Let ABC, *Fig. 11*, be a steelyard whose upper edge, BC, on which the sliding poise is carried, is horizontal. Let Z be the fulcrum knife-edge, and X and Y the knife-edges on which the load R and the principal weights Q hang respectively. Let G be the centre of gravity of the steelyard alone, whose weight is W. Let M be the position of the sliding poise, whose weight is P. The steelyard is supposed to be in equilibrium, with its graduated upper edge BC horizontal, under the action of these forces.

Since all the forces R, W, P, and Q, which act upon the steelyard, are vertical forces, and will always be vertical as the steelyard turns about its fulcrum Z, they may be regarded as weights of the same amounts collected at the points X G M and Y, at which they severally act. Let H be the centre of gravity of the weights supposed collected at the points G M and Y. Then the steelyard is in equilibrium under the action of the weight $W + P + Q$, acting at the point H on one side of the fulcrum Z, and the weight R acting at the point X on the other side of the fulcrum Z. Join the points X and H by the straight line XH. Then, if the line XH is above the fulcrum Z, the balance is un-

stable. For if both the points X and H are above the horizontal line through Z, then, as the steelyard turns about the point Z and the end C rises, the leverage of the weight R on the left-hand side of the fulcrum will increase, and the leverage of the weight $W + P + Q$, on the right-hand side of the fulcrum, will diminish. And if one of the points, as X, be above the horizontal line through Z, and the other, as H, be below it, then as the end C of the steelyard rises, the leverage of the weights at X and H will both increase, but that at X will increase more rapidly than that at H. And lastly, if one of the points, as X, be below the horizontal line through Z, and the other, as H, be above it, then as the end C of the steelyard rises, the leverage of the weights at X and H will both diminish, but that at X will diminish less rapidly than that at H. If the end C of the steelyard drops, it may be shown in the same manner that the leverage of the weight $W + P + Q$ at H will always increase relatively to that of R at X. So that in all cases, if the line XH be above the fulcrum Z, the balance will be

Fig. 11.



unstable, and the steelyard will be "accelerating," that is to say, with the very smallest excess of moment on the left-hand side of the fulcrum, the end C of the steelyard will rise, and will ascend with accelerating velocity till it is brought up by a stop of some sort; and with the smallest excess of moment on the right-hand side of the fulcrum, the end C of the steelyard will drop, and will descend with accelerating velocity till it is brought up by a similar stop. If the line XH be below the fulcrum Z, then it may be shown by exactly similar reasoning that in all cases the balance is stable and the steelyard is "vibrating," that is to say, the steelyard will sway or vibrate up and down past the horizontal line through Z, and will ultimately come to rest in that position.

Since the weight Q and the position of the sliding poise will vary according to the load R, the position of the point H will vary also. As it would be manifestly inconvenient that the steelyard should be sometimes "accelerating" and at other times "vibrating," it will be necessary to arrange the knife-edges so that the steelyard shall either be accelerating for all values of R

within the capacity of the steelyard, or vibrating for all values of R . There is no difficulty in doing this, and, speaking generally, if the knife-edges be placed in anything like mean positions (as in the diagram), the steelyard will be "accelerating" if the line joining X and Y is decidedly above Z , and will be "vibrating" if the same line is decidedly below Z .

If the line XH be above the fulcrum Z , then, as the knife-edges wear down, the line XH and the fulcrum Z will approach each other. Therefore for a given very small movement of the end C of the steelyard, the increased leverage on the one side or the other of the fulcrum will be less than it was before, and the accelerating effect will be less vigorous and pronounced than it was before. Consequently it will be easier to adjust the sliding poise, so as to weigh to a greater degree of delicacy than before. Thus, from this cause the delicacy of the balance is increased just in proportion as it is diminished from the increased dulness and friction of the knife-edges, and the consequent sluggishness of the balance. But if the line XH be below the fulcrum Z there is no such compensating effect, for as the knife-edges wear down, the line XH and the fulcrum Z recede from each other. Consequently the vibrating effect will be more vigorous and pronounced than it was before, and the sensitiveness and delicacy of the balance will be less, and the increased dulness of the knife-edges will add to this want of delicacy. Thus it might be expected that the knife-edges of an accelerating steelyard would wear longer than those of a vibrating steelyard before it was found necessary to sharpen them.

As regards the relative merits of the two systems, the accelerating steelyard is quicker in its action than the vibrating steelyard, and has the advantage in respect of the wear of its knife-edges mentioned above. But when the knife-edges are in good condition, and the steelyard in good adjustment, the vibrating steelyard will probably weigh to a greater degree of nicety than the accelerating steelyard. Also in the case of a steelyard forming part of a platform machine, it will be seen hereafter (see pages 43 and 44) that a vibrating steelyard has an important advantage in being less affected by tilting the machine out of level than an accelerating steelyard.

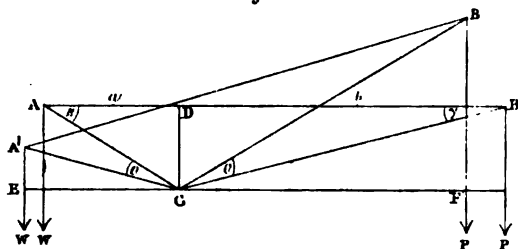
All the foregoing remarks have reference to steelyards made with good knife-edges, hard and true bearings, and general accuracy of workmanship, such, for example, as those fitted to platform machines. For the rough and cheap steelyards commonly made, it is found necessary to make them accelerating, in order to overcome the inherent sluggishness of the machine, and this is probably

the most accurate, as well as the quickest, method for such machines.

Effect of Displacing a Steelyard from its Position of Equilibrium.—

Let $A B C$, *Fig. 12*, be an accelerating steelyard, of which A is the knife-edge on which the load W is hung, B the point at which the weights on the right-hand side of the fulcrum may be supposed to be collected (corresponding to the point H in the diagram on page 29), and C the fulcrum. And let $A B C$ be the position of equilibrium of the steelyard, with the line $A B$ horizontal, when weights W, P , are hung at A and B . Let $A' B' C$ be the displaced position of $A B C$ after turning about the fulcrum C through an angle (θ) , and complete the Figure. Then the moment of W acting at $A' = W \times E' C = W \times A' C \cos (\beta - \theta) = W \times \frac{a}{\cos \beta} \cdot \cos (\beta - \theta)$. And the moment of P acting at $B' = P \times F' C$

Fig. 12.



$= P \times B' C \cos (\theta + \gamma) = P \times \frac{b}{\cos \gamma} \cdot \cos (\gamma + \theta) = W \times \frac{a}{\cos \gamma} \cdot \cos (\gamma + \theta)$ (since $W \times a = P \times b$). The difference of these moments is—

$$\begin{aligned} & W a \left\{ \frac{\cos (\beta - \theta)}{\cos \beta} - \frac{\cos (\gamma + \theta)}{\cos \gamma} \right\} \\ &= W a \{ \cos \theta + \sin \theta \tan \beta - \cos \theta + \sin \theta \tan \gamma \} \\ &= W a \{ \tan \beta + \tan \gamma \} \sin \theta. \end{aligned}$$

Let this difference of moments be equal to that of a small weight (w) hung at B' , then—

$$\begin{aligned} w \times \frac{b}{\cos \gamma} \cos (\gamma + \theta) &= W a (\tan \beta + \tan \gamma) \sin \theta, \\ w b (\cos \theta - \sin \theta \tan \gamma) &= W a (\tan \beta + \tan \gamma) \sin \theta, \\ w b (1 - \tan \theta \tan \gamma) &= W a (\tan \beta + \tan \gamma) \tan \theta, \\ w &= W \frac{a}{b} \cdot \frac{(\tan \beta + \tan \gamma) \tan \theta}{1 - \tan \theta \tan \gamma}. \end{aligned}$$

For any moderate amount of displacement, the denominator will be $+$. If, therefore, (θ) is $+$, (w) is $+$, and increases positively with (θ) ; and if (θ) is $-$, (w) is $-$, and increases negatively with (θ) . Therefore, when an accelerating steelyard is displaced, so that its long arm is raised above its position of equilibrium, a greater weight is required to be hung at B' , to bring it back, than was sufficient to keep it in its position of equilibrium; and when it is displaced so that the long arm is depressed below its position of equilibrium, a less weight is required to be hung at B' , in order to bring it back, than was necessary to keep it in its position of equilibrium.

In the case of a vibrating steelyard (β) and (γ) will both be $-$, and the effect of displacement will be the reverse of that in the case of an accelerating steelyard.

Examples of steelyards of different degrees of accuracy, and for different purposes, are shown in Plate 2, Figs. 1 to 3, and described on pages 56 to 58.

B. 2. BALANCES FORMED BY COMBINATIONS OF UNEQUAL-ARMED LEVERS AND STEELYARDS, SUCH AS PLATFORM MACHINES, WEIGHBRIDGES, &c.

These are the machines commonly used to weigh loads exceeding 2 cwt. The power applied at the end of the steelyard is multiplied by the levers from one hundred to five hundred times, and therefore the weights used are small and handy. The load is, in the first place, commonly received upon four knife-edges, so that on the average each knife-edge receives only one-fourth of the load. Consequently the strains upon the parts for a given load are much less than in the case of scale-beams. The gain in compactness over scale-beams and dead-weight machines is very great; for, in the first place, the load is received steadily upon the four knife-edges, and no legs and stays are required to preserve the equilibrium. In the next place the levers, by means of which the pressure is transferred to the steelyard, take up but little room, and by ingenious arrangements, such as that shown in Plate 2, Figs. 6, the machine may be rendered remarkably compact. And lastly, since the vertical movement of the end of the steelyard is from one hundred to five hundred times greater than that of the platform, there is abundant movement of the steelyard to ascertain the weight of the load for an almost infinitesimal movement of the platform. The vertical pillar usually attached to platform

machines is merely added for convenience of reading the steelyard, and is not essential to the action of the machine. And when great compactness is of the first consequence, the steelyard may be arranged alongside of the platform casing, or made to pass close over the platform levers, so as to occupy little or no more vertical space than the platform levers themselves. As regards accuracy, all that has been said on page 24 concerning the accuracy of simple steelyards applies in an enhanced degree to platform machines, by reason of the greater number of levers and knife-edges, and the greater chance of error. But the construction is so simple, and the work in general so good, that they are very accurate. An error of about 1 oz. per cwt. is as much as a new platform machine would commonly show.

When the bulk or weight of the goods to be weighed are such that the weighing machine must be very heavy, portable weighbridges or platform machines are inapplicable, and it is necessary to erect the weighbridge on a solid foundation. In such cases, very great compactness is not of the first consequence. The principle of the lever arrangement is the same as that of the platform machines; but when, as is generally the case, the weighbridges are used for weighing carts, railway trucks, &c., the pillar with its steelyard must be moved away from the weighbridge, and to one side of it, so as not to obstruct the vehicle that is to be weighed. Consequently, it is necessary to arrange the levers somewhat differently from those of a platform machine, and in different ways according to the length of the weighbridge and the weight which it has to carry. For weighbridges are sometimes made 40 feet long, and to weigh up to 100 tons. In such cases, the machine would practically be doubled, and the load would be received on eight knife-edges instead of four, as in the example shown in Plate 2, Fig. 9. Assuming that a weighbridge is skilfully made and carefully erected on a good foundation, it ought to weigh with great accuracy. For there is no friction but knife-edge friction, and errors due to want of level ought not to exist. A first-class weighbridge when new, with 30 tons upon it, ought to be sensitive to 2 lbs., and to show no greater error than 4 lbs. or 5 lbs. But it would not be so accurate after wear, though with good usage they are very durable machines. A very useful application of weighbridges is to ascertain the exact weights on the separate wheels of locomotive engines, so that they may be properly adjusted. For this purpose a number of separate weighbridges of simple construction are erected, one for each wheel of the engine, with their running surfaces in exactly the same horizontal plane;

the engine is moved on to them, and the pressures of all the wheels are taken simultaneously each by its own weighbridge.

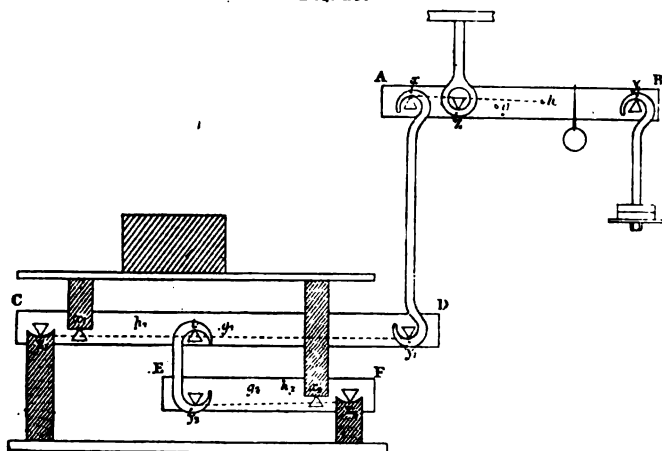
Platform machines, like simple steelyards, may be arranged either on the "accelerating" principle, or on the "vibrating" principle. In practice, there is a wide difference between the two systems; each has its advantages, and some manufacturers prefer the one and some the other. The problems relating to them will chiefly arise out of the different principles on which they are arranged. A special set of problems are those relating to the effect of tilting platform machines out of level in different directions, and these will lead to some curious and important results.

On the Conditions necessary for a Platform Machine to be "accelerating" or "vibrating."—The usual arrangement of the levers of a platform machine is as in *Fig. 13*; but the steelyard AB, which is generally placed at right-angles to the body levers, is shown in the same line with them for convenience of demonstration. A drawing to scale of a platform machine will be found in Plate 2, *Figs. 5*. The platform and the load upon it are carried on four knife-edges, two of which, x_1 and x_2 , are shown, and the load is transferred to the steelyard by the two levers shown, the upper one CD, being known as the "long body," and the lower one EF, the "short body." If the distance $z_1 x_1$ between the fulcrum and load knife-edges of the long body be equal to the distance $z_2 x_2$ between the fulcrum and load knife-edges of the short body, and the distance $z_1 t$ be equal to the distance $z_2 y_2$, then the leverage of any portion of the load applied at x_2 will be the same as the leverage of any portion of the load applied at x_1 , and the pressure produced at y_1 , will be the same for equal portions of the load, whether they were originally applied at x_1 or x_2 . Therefore, it is immaterial whether the load is applied equally on the four knife-edges or not. The machine will register the true weight of the load, however it is placed upon the platform, which is a matter of the most vital consequence for such machines.

Let AB be the steelyard with its three knife-edges $x y z$; CD the long body with its three knife-edges $x_1 y_1 z_1$, and the knife-edge t on which the short body is hung; EF the short body with its three knife-edges $x_2 y_2 z_2$. The conditions are that $z_1 x_1 = z_2 x_2$ and $z_1 t = z_2 y_2$. The conditions necessary for the steelyard AB to be "accelerating" or "vibrating," have been investigated on pp. 28 to 30. And if the knife-edges of the steelyard have been arranged so as to render it "accelerating," then when the weights acting at (y) and the sliding poise have been properly adjusted, and supposing that there is a very small excess of moment on the left-hand side

of the fulcrum, the long arm of the steelyard will just rise and continue to rise at an accelerated rate. Let the equilibrium of the long body CD be now considered. Let g_1 be the centre of gravity of the long body. Then as before, the three vertical forces acting downwards on the lever, viz., its weight acting at the point g_1 , the part load of the platform, &c., acting at the point z_1 , and the pull of the short body acting at the point t , may be regarded as weights collected at the same points. Let h_1 be the centre of gravity of the three weights. Then the long body is in equilibrium under the action of the three weights supposed collected at the point h_1 acting downwards, and the upward pull of the rod xy_1 acting at y_1 . Join the points $z_1 y_1$ by the straight line $z_1 y_1$.

Fig. 13.



Then if the point h_1 be above the line $z_1 y_1$, and the end D of the long body descends, we have the three following cases: First, if h_1 and y_1 are both above the horizontal through z_1 , then as the long body descends, turning about the point z_1 , the leverage both of the short arm $z_1 h_1$, and of the long arm $z_1 y_1$ will increase, but the leverage of the short arm will increase at a quicker rate than that of the long arm; secondly, if y_1 is in the horizontal through z_1 , then the leverage of the short arm will increase, while that of the long arm will diminish; and thirdly, if both h_1 and y_1 are below the horizontal through z_1 , then the leverage both of the short arm and of the long arm will diminish; but the leverage of the short arm will diminish at a slower rate than that of the long arm. So that in all three cases the leverage of the short arm increases

relatively to that of the long arm, and the weights supposed collected at the point h_1 overcome the power at y_1 more and more easily as the end D descends, and accelerate the upward movement of the long arm of the steelyard. And by similar reasoning it can be shown that if the point h_1 be above the line z_1y_1 , and the end D of the long body ascends, then in all cases the leverage of the short arm diminishes relatively to that of the long arm. Therefore, this arrangement of the knife-edges of CD favours the "acceleration" principle, or is suited to act with and assist an "accelerating" steelyard. If, on the contrary, the point h_1 be below the line z_1y_1 , then as the end D descends, the leverage of the short arm diminishes relatively to that of the long arm. Therefore, the weights supposed collected at h_1 overcome the power at y_1 less and less easily as D descends, and tends to make the steelyard recover its horizontal position. Therefore, this arrangement of the knife-edges of the long body favours the "vibration" principle, or is suited to act with and assist a "vibrating" steelyard.

As regards the equilibrium of the short body EF. Let g_2 be the centre of gravity of the short body, and let h_2 be the centre of gravity of the weight acting at g_2 , and a weight equivalent to the vertical pressure of the part load of the platform, &c., acting at x_2 . As the end D of the long body descends, the end E of the short body will also descend. And exactly as before, it may be shown that if the point h_2 be above the line z_2y_2 , the leverage of the short arm z_2h_2 increases relatively to that of the long arm z_2y_2 . And therefore as the end D descends, the pull upon CD at the point t increases. Consequently this arrangement of the knife-edges of the short body favours the "acceleration" principle. And if the knife-edges be arranged so that the point h_2 is below the line z_2y_2 , then this arrangement favours the "vibration" principle.

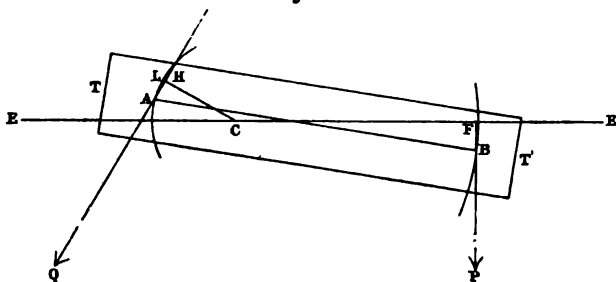
The remarks on page 30, concerning the effect of the wear of the knife-edges on the acceleration or vibration of the steelyard, and the delicacy of the balance, will apply precisely to the knife-edges of the long and short bodies.

Speaking generally, if the knife-edges of the steelyard be arranged so that the line joining x and y is decidedly above the fulcrum z , the steelyard will always be "accelerating": if the knife-edges of the long body are arranged so that the points x_1 and t are decidedly above the line z_1y_1 , the long body will always be "accelerating": and if the knife-edges of the short body be arranged so that the point x_2 is decidedly above the line z_2y_2 , the short body will always be "accelerating." And if arranged in the reverse way, they will all be "vibrating."

Effect of tilting a Platform Machine in the direction of the Steelyard on the "Acceleration" or "Vibration" of the Steelyard.—Definition of "tilting in the direction of the long arm of the steelyard," &c., in this and subsequent investigations. Suppose that a person is standing on the middle of the platform and looking towards the steelyard. In the machines as usually constructed the pillar will be centrally in front of him, and the long arm of the steelyard will project either towards the right or towards the left (see Plate 2, Fig. 5). Suppose that it projects towards the right, then by "tilting in the direction of the long arm of the steelyard" is meant that the machine is tilted as it would be by wedges thrust under the left-hand side of the machine, and by "tilting in the direction of the long arm of the long body lever" is meant that the machine is tilted as it would be by wedges thrust under the front edge of the machine, which is behind the person standing on the platform.

Let $T T'$, Fig. 14, be an "accelerating" steelyard in its position

Fig. 14.



of equilibrium after the machine has been tilted in the direction of the long arm of the steelyard. The effect of tilting the machine is to tilt the direction of pull of the suspension rod, and it will be seen hereafter (see pages 39 to 41) that the position of equilibrium of the steelyard, when the pull of the suspension rod is in the direction AQ , will be something like that shown in the figure.

A is the knife-edge which receives the pull of the suspension rod, B the point at which the weights on the right-hand side of the fulcrum may be supposed collected, corresponding to the point H in the diagram on page 29, and C the fulcrum knife-edge, which will be below the line AB . The steelyard is in equilibrium under the action of the force Q pulling at the point A in the direction AQ , and the force P acting vertically at the point B . From the centre C describe arcs of circles representing the paths of

the points A and B. Draw CH perpendicular to QA produced, and produce CH to meet the circle in L. Then the greatest possible leverage of the force Q is CL, and its actual leverage in the diagram is CH. Draw the line ECE horizontal and produce PB to meet it in F. Suppose now that the end T' of the steelyard is swayed upwards; then the leverage of P about C increases, and the leverage of Q about C diminishes. Therefore the end T' of the steelyard will sway downwards and endeavour to recover its original position. If the end T' be swayed downwards then the leverage of P about C diminishes, and that of Q about C increases. Therefore the end T' of the steelyard will sway upwards and endeavour to recover its original position. And therefore the steelyard is a vibrating one, and the effect of tilting the machine in the direction of the long arm of the steelyard (which tilted the direction of the force pulling at A) has been to change it from an "accelerating" steelyard to a "vibrating" steelyard. This would render the machine useless for accurate work, as the arrangement of the frame is adapted either for "acceleration" or "vibration," but not for both.

The amount of tilt which would render an "accelerating" machine "vibrating" will depend on the positions of the knife-edges. For a very small angle of tilt the effect would be to make the acceleration more dull and sluggish, and this would increase with the angle of tilt till the machine became vibrating.

In the same way it can be shown that if the machine be tilted in the opposite direction to that considered above, the effect on an accelerating steelyard would be to make it much more accelerating than before, which would diminish the sensitiveness of the machine and render it less accurate for weighing purposes.

If the same reasoning be applied to the case of a "vibrating" machine, it can be shown in a similar manner that the effect of tilting the machine in the direction of the long arm of the steelyard will be to render it more "vibrating" than before. The number of vibrations in a minute will be largely increased, and the machines will be less delicate and accurate. If the machine be tilted in the opposite direction the "vibrating" machine will be changed to an "accelerating" machine, and will become unfit for accurate work and the arrangement of the frame.

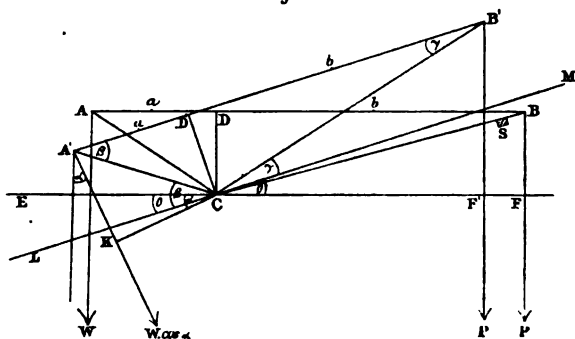
If the steelyard be neither accelerating nor vibrating, i.e., if the points A, C, and B be in the same straight line, then if the machine be tilted in the direction of the long arm of the steelyard, the steelyard will become "vibrating," and if tilted in the opposite direction it will become "accelerating." But, as will be seen

hereafter (see page 41), no effect will be produced on the apparent weight of the goods on the platform—a result well worthy of notice.

Effect of tilting a Platform Machine in the direction of the Steelyard on the apparent Weight of the Goods on the platform.—When the machine is level the pull upon the short arm of the steelyard is vertical, and the steelyard is properly adjusted to weigh the goods when its position of equilibrium is horizontal. But when the machine is tilted the pull upon the short arm is altered both in amount and direction, and the position of equilibrium of the steelyard will be altered, assuming that the weights on the long arm are not shifted. The new position of equilibrium will depend upon the arrangement of the knife-edges, and will be very different according as the steelyard is “accelerating” or “vibrating.”

Let A B C, *Fig. 15*, be an accelerating steelyard, of which A is the knife-edge which receives the pull of the suspension-rod, B

Fig. 15.



the point at which the weights on the right-hand side of the fulcrum may be supposed collected, corresponding to the point H in the diagram on page 29, and C the fulcrum knife-edge which will be below the line A B. Let it be assumed that the line A B is horizontal when the machine is level, and that the steelyard is in equilibrium under the action of the vertical loads W and P acting at the points A and B respectively. In this state the long arm of the steelyard is just able to rise from the stop S on the frame, which defines the position of horizontality when the machine is level. Draw C D perpendicular to A B, and let $A D = a$, $B D = b$, the angle $C A D = \beta$, and the angle $C B D = \gamma$. Since the steelyard is in equilibrium we have $W \times a = P \times b$.

Now let the machine be tilted in the direction of the short arm of the steelyard through an angle (α), and let $A'B'C$ be the

position of equilibrium of the steelyard under the altered conditions, so that the line $A'B'$ is inclined at an angle (θ) to the horizontal. Let the line ECF be horizontal, and draw LCM parallel to $A'B'$, and complete the figure. In consequence of the tilting the pull at A' is changed from W to $W \cos \alpha$, and it acts in the direction $A'K$. Draw CK perpendicular to $A'K$. Then for equilibrium there must be—

$$W \cos \alpha \times CK = P \times CF'$$

$$CK = A'C \cos A'CK = \frac{a}{\cos \beta} \times \cos (\alpha + \beta - \theta)$$

$$CF' = B'C \cos B'CF' = \frac{b}{\cos \gamma} \times \cos (\gamma + \theta)$$

$$\therefore W \cos \alpha \times \frac{a}{\cos \beta} \cos (\alpha + \beta - \theta) = P \times \frac{b}{\cos \gamma} \cos (\gamma + \theta)$$

$$\text{But } Wa = Pb,$$

$$\therefore \frac{\cos (\alpha + \beta - \theta)}{\cos (\gamma + \theta)} = \frac{\cos \beta}{\cos \alpha \cos \gamma}.$$

Omitting the details of the work, this equation gives finally

$$\tan \theta = \frac{\tan^2 \alpha + \tan \alpha \cdot \tan \beta}{\tan \gamma + \tan \gamma \tan^2 \alpha + \tan \alpha + \tan \beta} \quad \text{Now } (\theta) \text{ will be}$$

greater or less than (α) according as $\tan \theta$ is greater or less than

$$\tan \alpha, \text{ i.e., according as } \frac{\tan^2 \alpha + \tan \alpha \cdot \tan \beta}{\tan \gamma + \tan \gamma \tan^2 \alpha + \tan \alpha + \tan \beta} \text{ is}$$

greater or less than $\tan \alpha$, or as $\tan^2 \alpha + \tan \alpha \cdot \tan \beta$ is greater or less than $\tan \alpha \cdot \tan \gamma + \tan \gamma \tan^3 \alpha + \tan^2 \alpha + \tan \alpha \tan \beta$, or as 0 is greater or less than $\tan \alpha \tan \gamma + \tan \gamma \tan^3 \alpha$, which is always real and $+$. Therefore (θ) is $+$ and less than (α) ; i.e., for equilibrium the long arm of the steelyard must not be elevated through so great an angle as (α) . But the steelyard arm will be elevated at least as much as (α) by reason of the stop S , which will carry it up along with it. Therefore the long arm of the steelyard is elevated above its position of equilibrium, and, as is shown on page 32, a greater power on the long arm of the steelyard than is necessary to maintain it in its position of equilibrium would be required to keep it down on the stop. Consequently the apparent weight of the goods on the platform is greater than the real weight, and the machine when tilted in the direction of the short arm of the steelyard will be against the purchaser.

In order to find the effect of tilting the machine in the direction of the long arm of the steelyard, write $-a$ for a in the equation

for $\tan \theta$. Then it will appear that (θ) is $-\alpha$ and less than (α) ; i.e., for equilibrium the long arm of the steelyard must be depressed below the horizontal position, but not through so great an angle as (α) . If therefore it be depressed down upon the stop, then, as is shown on page 32, a smaller power on the long arm of the steelyard than is required to keep it in equilibrium will suffice to keep it down on the stop. Therefore the sliding poise must be shifted towards the fulcrum, so that the long arm may just rise, and no more, from the stop. Therefore the apparent weight of the goods on the platform is less than the real weight, and the machine when tilted in the direction of the long arm of the steelyard is in favour of the purchaser.

In the case of a vibrating steelyard, the fulcrum C is above the line A B, and for equilibrium the steelyard is adjusted so that a beak or pointer attached to the end of the long arm shall be exactly opposite a similar pointer attached to the frame. In exactly the same way as above, it may be shown that when the machine is tilted in the direction of the short arm it is in favour of the purchaser, and when tilted in the opposite direction is against the purchaser.

If the steelyard be neither accelerating nor vibrating. i.e., if the points A, C, and B, be in the same straight line, the position of equilibrium of the steelyard is found by putting $\beta = 0$, $\gamma = 0$, in the equation for $\tan \theta$. And it then appears that $\tan \theta = \tan \alpha$, and $\theta = \alpha$. Therefore the position of equilibrium of the steelyard exactly follows the tilting of the machine, and there will be no alteration of the apparent weight of the goods on the platform for any angle of tilt.

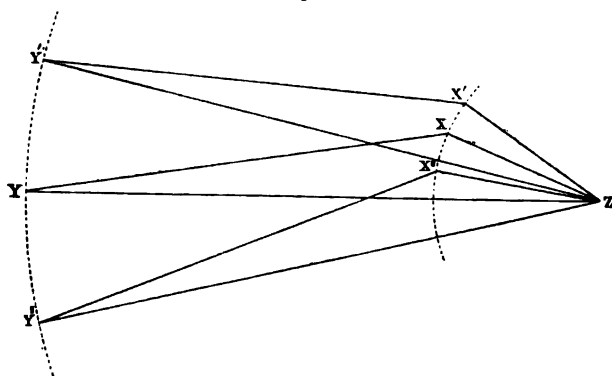
Effect of tilting a Platform Machine in the direction of the long body lever on the Apparent Weight of the Goods on the Platform.—In a platform machine, as usually constructed, the long body lever is freely hung by its ends, at one end from the short end of the steelyard by the suspension-rod, and at the other end from a fixed bracket of the lever-box by a shackle. When the machine is level the long body lever is horizontal, and the suspension-rod and shackle are vertical. But when the machine is tilted in the direction of the long body, the long body lever takes up an inclined position of equilibrium, and the suspension-rod and shackle become slightly inclined to the vertical. In consequence of the tilting, the vertical pull on the short arm of the steelyard will be altered, and this effect is mainly due to the arrangement of the knife-edges of the long body lever.

Suppose that the knife-edges of the long body lever are arranged

on the accelerating principle (see diagram on page 35, and the accompanying text), *i.e.*, that the point of application of the weights is above the line joining the knife-edges at the two ends of the lever.

Let XYZ , *Fig. 16*, be the long body lever in its horizontal position, Z being the fulcrum knife-edge which is carried by the shackle, Y the knife-edge carried by the suspension-rod, and X the centre of gravity of the weights which act upon the long body (corresponding to the point h_1 in the diagram on page 35). And let $X'Y'Z$, $X''Y''Z$, be the positions of the lever when the machine is tilted in one direction or the other. Then it is seen that as the lever moves from the position XYZ to the position $X'Y'Z$, the leverage of the weights supposed collected at X continually diminishes, and the leverage of the vertical pressure at Y also continually

Fig. 16.



diminishes. But the leverage of X diminishes at a more rapid rate than that of Y . Therefore the effect of tilting the machine so that the long body lever assumes the position $X'Y'Z$, is to increase the vertical pressure at Z , and to diminish the vertical pressure at Y' . And therefore for the equilibrium of the steelyard it would be necessary either to make a small addition to the load on the platform, or to shift the sliding poise towards the fulcrum, so as to diminish its leverage. If the machine was tilted in the opposite direction, so that the lever assumed the position $X''Y''Z$, then it is seen that as the lever moves from the position XYZ to the position $X''Y''Z$, the leverage of the weights supposed collected at X continually increases, and that of the vertical pressure at Y continually diminishes. Therefore the vertical pressure at Z

diminishes, and the vertical pressure at Y" increases. And therefore for the equilibrium of the steelyard a small portion of the load on the platform must be taken off, or the sliding poise must be run out so as to exercise greater leverage.

If the knife-edges of the long body are arranged on the "vibrating" principle, i.e., if the point X is below the line joining Y and Z, then in the same way it can be shown that the effect on the equilibrium of the steelyard for either direction of tilt is exactly opposite to that produced by the accelerating arrangement. But in general, with a lever arranged on the vibrating principle, the points X, Y, Z, are so nearly in a straight line, that the effect of a moderate amount of tilting is very small, and far less marked than in the case of levers arranged on the "accelerating" principle.

Thus, if an accelerating platform machine be tilted in the direction of the long arm of the long body lever, the machine is against the purchaser, and if it be tilted in the opposite direction it is in favour of the purchaser. And the reverse will be the case with a vibrating machine. If the long body lever be neither accelerating nor vibrating, i.e., if the points X, Y, and Z are in the same straight line, then there will be no alteration of the vertical pressure at Y for any angle of tilt.

Summing up the conclusions arrived at with respect to tilting platform machines out of level, it appears as follows:—

- (1.) If the steelyard is "accelerating," and the machine is tilted in the direction of the long arm of the steelyard, the steelyard will become "vibrating," and the machine when so tilted is in favour of the purchaser. If the machine is tilted in the opposite direction, the steelyard will become more strongly "accelerating," and the machine when so tilted is against the purchaser.
- (2.) If the steelyard is "vibrating," and the machine is tilted in the direction of the long arm of the steelyard, the steelyard will become more strongly "vibrating," and the machine when so tilted is against the purchaser. If the machine is tilted in the opposite direction, the steelyard will become "accelerating," and the machine when so tilted is in favour of the purchaser.
- (3.) If the steelyard is neither "accelerating" nor "vibrating," and the machine is tilted in the direction of the long arm of the steelyard, the steelyard will become "vibrating," but the machine will be neither in favour of nor against

the purchaser. If the machine is tilted in the opposite direction, the steelyard will become "accelerating," but the machine will be neither in favour of nor against the purchaser.

- (4.) If the long body lever is "accelerating," and the machine is tilted in the direction of the long arm of the lever, the machine when so tilted is against the purchaser. If the machine is tilted in the opposite direction it will be in favour of the purchaser.
- (5.) If the long body lever is "vibrating," and the machine is tilted in the direction of the long arm of the lever, the machine when so tilted is in favour of the purchaser. If the machine is tilted in the opposite direction, it will be against the purchaser.
- (6.) If the long body lever is neither "accelerating" nor "vibrating," and the machine is tilted either in the direction of the long arm of the lever or in the opposite direction, it will not be sensibly either in favour of or against the purchaser.

As regards the amount by which platform machines when tilted are in favour of or against the purchaser, the experiments of the Author on a number of portable machines having a capacity of 4 or 5 cwt., show that in general the effect of tilting is much greater on "accelerating" machines than on "vibrating" machines. The reason of this is that in the case of a vibrating machine the points A, B, C in *Fig. 15*, and the points Y, X, Z, in *Fig. 16*, are in general almost exactly in the same straight line. In the case of accelerating machines, the effect of tilting the machine in the direction of the steelyard by means of a $\frac{1}{2}$ -inch wedge (corresponding to an angle of tilt of about $1^{\circ} 12'$), would sometimes amount to 12 oz. when the machine was loaded to its full capacity. But the effect of tilting the machine in the direction of the long body lever by means of a $\frac{1}{2}$ -inch wedge, would sometimes amount to 20 ozs. when the machine was loaded to its full capacity. These quantities are very large, when it is considered that the total error allowed on such machines when loaded to their full capacity would not be more than 4 or 5 ozs. And it may be remarked that the amount of tilt produced by a $\frac{1}{2}$ -inch wedge might easily escape notice unless checked by means of a spirit-level.

As regards the testing of platform machines, the first thing to be done is to ascertain that the machine is placed on a permanent and solid foundation, and that it is truly level, the neglect of

which precaution may vitiate the entire testing, and lead to the condemnation of a machine which is in all essential respects correct. It is, of course, necessary that the indication of the steelyard should be very nearly the same, whether the load is piled entirely upon the centre, or over any one of the four knife-edges which carry the platform. Having found by trial the place for which the error is greatest, weights should be piled there up to the full capacity of the machine. The cause of error is in general a very slight discrepancy in the distances between the load and fulcrum knife-edges at the different corners, and therefore the error will increase proportionally with the load, so that if the error is 2 oz. for $\frac{1}{2}$ cwt., it will be 16 oz., or 1 lb., for 4 cwt., and so on. If with the maximum load the error is greater than is allowed for the class of machine in question, then the machine must be rejected, and the knife-edges re-adjusted. The testing-weights ought to be flat at top and bottom, so that they can be piled one upon another. The loose weights, which are intended to be hung at the end of the steelyard, should be carefully weighed, and they ought to be consistent among themselves to a single grain weight, i.e., the weight intended to balance 28 lbs. on the platform, should be exactly double the weight of that intended to balance 14 lbs., that for 56 lbs. exactly double that for 28 lbs., and so on. For supposing, for example, that 1 lb. on the end of the steelyard balances 112 lbs. on the platform, then an error of 4 grains (which is an extremely small quantity) in any one of the steelyard weights will cause an apparent error in the machine of about 1 oz., and so for other errors. In dealing with such machines, the effect of the enormous leverage exerted by a weight hung at the end of the steelyard must always be borne in mind. In some machines there are no loose weights, but the power is applied by two sliding poises, one a heavy poise, for the bulk of the load, and the other a light poise, each with its own graduated scale. This arrangement has a distinct advantage, in respect that the weights on the steelyard are always the same, but the graduations would need to be very carefully marked. The amount of the total error allowable on platform machines has not been defined by the Board of Trade, and is left to be decided by the local authorities according to the purposes for which each machine is intended. In general, the amount of error allowed would be about 1 oz. per cwt., so that the error allowed on a machine whose maximum capacity is 4 cwt. would be 4 ozs. when fully loaded; this error would be the $\frac{1}{1792}$ part of the load weighed. For a discussion of the errors of trade machines, see pages 48 to 51.

Some platform machines are made "self-recording" by the following arrangement:—The steelyard is provided with a large and small sliding poise. Each of these poises carries a horizontal strip of metal, which is graduated by means of raised figures corresponding to those on the steelyard itself. These strips pass under a strong punching lever arranged on the frame of the machine. A card prepared for the purpose is introduced through a slit in the frame between the punch and the strips. When the poises have been adjusted to weigh a load on the platform the punch is operated by a strong pull, and the impression of the raised figures is left on the card. Thus the weight is recorded without reading the positions of the poises. Sometimes instead of the card a continuous roll of strong paper is used, and upon this roll the records of a large number of successive weighings are recorded, and read off afterwards at leisure. The paper is unwound from one roller and wound up upon another roller, being hitched forwards by an automatic arrangement a small distance each time the punch is used.

In another arrangement the self-recording parts are entirely enclosed in the sliding poise itself. They consist of certain disk-wheels with the figures upon their circumference. These disk-wheels are actuated through a pinion, which gears into rack-work along the top of the steelyard, and as the poise is moved along the steelyard the pinion and disk-wheels are moved accordingly. By proper arrangements the disk-wheels may be made to move so that the uppermost figures upon them correspond to the weight indicated by the position of the poise, and a smart compression by a lever will print the figures upon a card introduced for the purpose.

In constructing platform-machines different manufacturers have introduced various parts, such as loose rocking pieces over the knife-edges, &c., &c., which are not essential to the principle of the machines, and are introduced for the purpose of ensuring a very free and vertical pressure on the knife-edges and increasing the accuracy of the machine. The Author has not found that these contrivances have increased the accuracy of the machines to any extent that is important for the purposes for which such machines are usually intended. And all unnecessary parts should be avoided, as they add to the complexity of the machine. It must be borne in mind that these machines are generally used in places such as warehouses, railway platforms, &c., where there is much dust, and therefore it is advisable that the bearings of the knife-edges should not be recessed in any way so that dust can lodge

and be retained in them. Much oil is objectionable, as it speedily clogs up with the dust, and the only lubrication allowed should be a very little black lead. The knife-edges ought to be relieved from pressure whenever the machine is not in use. And for this purpose it is advisable that means should be provided for the throwing the machine out of gear by lowering the platform levers and thus allowing the platform to rest on the edges of the frame instead of upon the levers. This precaution is neglected in many of the machines that are made, and is the more important because these machines are commonly used in places where they are exposed to heavy shocks from loads being temporarily thrown upon them, &c. In order that a platform-machine may be in proper adjustment for weighing loads placed upon it, it is essential that the weight of the steelyard and parts attached to it, together with the sliding poise when at zero, should exactly balance the weight of the platform, levers, &c., and as this may vary a little with wear and dirt it is necessary to have a fine adjustment of the weight of the steelyard. This is usually done by a small weight such as a nut, at one end or other of the steelyard, which is carried on a fine screw, and can be run backwards or forwards as may be required till the weight of the steelyard exactly balances the dead weight of the platform and levers.

In Plate 2, Figs. 5 to 10, will be found examples of steelyards, platform machines, and weighbridges, in illustration of the remarks contained in the foregoing pages.

C. SPRING BALANCES.

These are the simplest, cheapest, and for many purposes the most convenient of all weighing-machines. They are extremely rapid in action, the indication is clear, and there is no need of loose weights excepting for testing the machine occasionally. Their action depends upon the extension of one or more spiral springs, and as the extension is proportionate to the weight which causes it the graduation is very simple. The amount of the extension for a given load depends upon the length of the spring, the diameter of the coil, and the thickness of the wire of which it is made, so that it is easy to design a spring to suit any purpose required. Springs can be combined in a variety of ways: sometimes one spiral spring is arranged to fit inside another spiral spring of larger diameter, and both acting together to carry the load. Sometimes a number of springs are arranged side by side, and all pulling together on one common bar, &c., &c. The accuracy of spring machines depends upon the accuracy of the

springs and the arrangement of the machines. The springs in general are wonderfully accurate and uniform in their action, and are very permanent if fairly well used; any error depending upon the springs would in general be very small. But if the extension of the spring is to be measured directly, and it very commonly is, by means of an index attached to the bottom of the spring, which plays past a graduated scale, then the range of the spring must be limited or else the machine becomes cumbersome. If, then, the spring is made stiff so as to carry a considerable weight with a moderate degree of extension, the accuracy to which the weight could be read on the scale will also be moderate. And if the spring is made weak so that a small weight will extend to it its extreme permissible limit then the reading will be accurate, but the total range of load small. Consequently for many purposes it is found convenient to use a tolerably stiff spring, and to indicate the extension (and consequently the load) by means of a small rack and pinion, which give motion to a finger on a dial-plate. This finger is frequently made to revolve two or three times completely for the full extension of the spring, and it is easy in this way to read to any degree of accuracy required. But the regularity and correctness of the indications of the finger will depend upon the condition of the rackwork and upon the friction, and these will vary with the wear of the machine.

It is found that when a spiral spring is extended by a weight it has a tendency to turn a little round its axis. Therefore, an index-pointer attached to the bottom of the spring and moving past a scale would rub slightly against the case. To correct this tendency the spring is sometimes made half with right-hand spiral and half with left-hand spiral.

From the extreme simplicity of these machines there is no need to give more than one or two examples, which are shown in Plate 2, Figs. 11 and 12, and described on pages 60 and 61.

On the Sensitiveness and Errors of Trade Balances.—This is a very important subject, for upon a clear understanding of it depends the administration of the law with respect to weighing-machines. The Board of Trade have not laid down any rules for the amount of error that may be allowed on trade balances; they have, indeed, in the "Model Regulations" issued by them, laid down certain rules for the "sensitiveness" of weighing-machines, but the sensitiveness is only a portion of the total error, and the real matter which requires authoritative decision, or at any rate recommendation, is the total amount of error that may be allowed on different trade weighing-machines. This point has been left

to the decision of the local authorities in the different districts, who are most unfitted for the duty, and the consequence is that there is much confusion. The inspectors of weights and measures who have to examine the trade balances used by the shopkeepers have no rule to go by, and are obliged to pass over many weighing-machines which show far too great an error, because they have found by experience that the magistrates (who are equally in the dark as to what amount of error ought to be allowed) will not convict unless the case is very flagrant. And on this matter each magistrate is a law for himself. It is evidently greatly to be desired that there should be one uniform law for the whole country as to the amount of error that should be allowed on trade balances of different kinds.

With regard to "sensitiveness," which as already stated is a portion, and a portion only, of the total error of a machine, "sensitiveness," as it is here understood, is measured by the weight required to make the balance sensibly turn when loaded to its full capacity. It is in fact a measure of the friction of the machine, and will depend entirely upon the workmanship, condition, and nature of the machine. If the machine is a scale beam (in which the friction consists entirely of knife-edge friction), and the knife-edges are sharp and hard, and the bearings hard and true, the sensitiveness of the machine will be very high, *i.e.*, a very minute weight will sensibly turn the scale, and the least weight that will do this is the greatest possible error due to "sensitiveness." If the machine be a counter machine, which from the greater number of separate knife-edges, and from the friction due to the stays, is not so delicate a machine as a scale beam, the error due to "sensitiveness" will be greater, and so for other machines. Moreover the "sensitiveness" of a machine will obviously depend upon its condition; if the knife-edges have been blunted by use, and if the machine is more or less dirty, it will not be so sensitive as when it was new.

But the total error of a machine involves many more considerations than that of mere sensitiveness. A machine may be extremely sensitive and yet the total error may be large. Take, for instance, a scale beam; the arms may be of unequal length or may be unequally balanced, the scale pans may be of unequal weight, and the machine generally out of adjustment; none of these matters affect the sensitiveness, but the total error may be very large. With counter-machines, in addition to all the possible errors of a scale beam, there are the possible errors due to faulty adjustment of the stays, &c. With steelyards there are

errors due to graduation, and so on. These errors are in general very much greater than those due to the friction, or sensitiveness, of the machines.

For practical purposes, *i.e.*, for ascertaining whether or no a given trade balance may be used for trade purposes, it is obviously immaterial what the "sensitiveness" of the machine may be, for it is only a portion, and generally only a small portion of the total error. What is wanted is to know what the total error that may be allowed on such a machine is. The total error should be stated as a fraction of the load, for the error will in general increase pretty uniformly with the load. And the maximum permissible errors should be stated both for machines that are new, and for machines that are not new but in a proper average condition of maintenance. The errors for new machines will be those which may be admitted for machines when presented for verification or stamping. The errors for machines in a proper average condition of maintenance will be those which may be admitted for machines which are in actual use for trade.

The Board of Trade, in their table relating to the "sensitiveness" of scale beams, counter-machines, spring balances, and steelyards, have divided them into Classes I, II, and III, and have allowed on Classes II and III four times and six times respectively the amount of error that is allowed on Class I according to the purposes for which the machines are supposed to be used. But in the first place there is no definition of the classes except by the "sensitiveness" errors (not the total errors) that the machines show, and in the next place it is utterly impossible to prevent the machines being used for other purposes than those originally stated.

It is suggested by the Author that there is no need of more than one class for each kind of trade balance. And, bearing in mind that the object of the inspection of trade balances is the protection of the public, and that so long as this object is sufficiently obtained it is not advisable to insist on a very high standard of accuracy, by reason of the cost of the machines and the inconvenience to the tradesmen, it is suggested that the following maximum errors for all trade machines, when new and presented for verification and stamping, might be admitted:—

Scale beams	$\frac{1}{2000}$ th of the load.
Counter-machines	$\frac{1}{1000}$ th "
Steelyards	$\frac{1}{500}$ th "
Platform machines	$\frac{1}{1000}$ th "
Weighbridges.	$\frac{1}{500}$ th "
Spring balances	$\frac{1}{100}$ th "

And for machines that have been previously stamped and are in actual use for trade purposes, it is suggested that they might be passed if their maximum errors did not exceed twice the amount of those stated in the table above.

On the Existing System of Inspection of Trade Balances.—For the prevention of fraud and for the regulation of trade balances, inspectors of weights and measures have been appointed by the local authorities throughout the kingdom. They are furnished with standard weighing-machines and weights duly verified by the Standards Department of the Board of Trade, and with all necessary apparatus for the performance of their duties. Their duties are to test all weighing-machines and weights intended for use in their district, and to stamp them if found correct within the permitted limits of error. It is illegal to use for trade purposes any machine or weight which has not been stamped as correct. Further it is the duty of the inspector to make periodic visits at irregular times throughout his district, and to see that the weighing-machines are not used in a fraudulent manner; and where he detects fraud to report such cases to the authorities for prosecution. It is easy to see that such duties are in many cases difficult and invidious, and the degree of efficiency with which they can be performed depends entirely upon the tact and ability of the inspector. A large proportion of the small shopkeepers in crowded towns are disposed to practise petty frauds, and in many trades it is a rare thing to find a trade balance which is not slightly against the purchaser. Such persons look upon the inspector as their natural enemy, and the word is rapidly passed when it is known that he is in the neighbourhood, and the fraudulent machines are speedily adjusted.

It is evident that under such a system, and especially where the inspectors are not men of good judgment and great activity, a large amount of fraud escapes detection. And it has long appeared to the Author doubtful whether it is the best system that could be adopted. The domiciliary visits of the inspector are naturally unpleasant and objectionable, and the districts are so large that it is impossible to inspect all parts so frequently and so thoroughly as to stamp out fraud. Moreover, the gain to the shopkeepers effected by the systematic use of balances which are slightly against the purchaser is so great, and the penalties for fraud even when it is detected, are so small, that there is a large temptation to cheat the poor. And it must be remembered that it is the poor who get cheated, and who need protection. For the poor have no balances to check the weight of their

purchases, and in that matter are very much at the mercy of the shopkeepers.

Thirteen years ago, the Author addressed a letter to the Board of Trade, in which was suggested a totally different system of preventing fraud, which still appears to him far more likely to be efficient than the existing system, and would be free from the objectionable domiciliary visits of inspectors. The plan suggested was to establish and maintain public weighing-machines at suitable places, and in sufficient numbers throughout the large towns, but especially in the poorer districts. Probably the best form of machine for the purpose would be spring-balances, which take up but little room, and could be readily fixed in walls. These machines would be very unobtrusive, and not liable to any but malicious injury; but they would need, at any rate at first, to be placed under the protection of the police, and to be regularly inspected and adjusted by the inspector of weights and measures. They would be open to the use of any one who chose to use them, without supervision of any kind, and of course, gratuitously. With this ready check upon their proceedings, it would be useless for the dealers to attempt fraud, for it would be immediately detected. And in addition to the chance of prosecution, for which they care little, they would lose custom, for which they care a great deal. And in the opinion of the Author, the result would be that every purchase would be then slightly over-weight instead of being slightly under-weight, as it is now.

And this would be effected without a single domiciliary visit by the inspectors. In fact, that portion of the inspectors' duties would be exchanged for the duty of inspecting and adjusting the public machines. In Appendix II will be found a copy of the letter referred to (which was printed by order of Parliament), in which the scheme is more fully explained.

The communication is accompanied by forty-two illustrations, from which Plates 1 and 2 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

DESCRIPTION OF THE MACHINES FIGURED ON PLATES 1, AND 2.

Scale Beam with Swan-neck Ends (Plate 1, Figs. 1).

This is a very common form of beam, and is in great use by ironmongers and many other tradesmen. It is cheaply made, and when in good adjustment is very accurate. The swan-neck end of the beam is spread out to a width sufficient to allow the knife-edge to be formed in it, a piece of steel having been welded into the iron end for the purpose. From the bent form of the swan-neck end it is easy to adjust the arms for length with very great accuracy by a slight blow with a hammer, but this is not an unmixed advantage as an accidental blow may easily throw it out of adjustment. The fulcrum knife-edge is formed in a piece of steel which is welded into a small block of iron, and is driven through a hole in the beam and takes bearing on both sides. This construction is to avoid the brittleness which would result if the whole block were made of steel and hardened. This form of beam is not commonly used where great accuracy is required.

Scale Beam with Box Ends (Plate 1, Figs. 2).

This is one of the commonest types, and is used for beams of all sizes up to a capacity of 1 cwt. or thereabouts, and for almost all purposes according to the degree of care and finish with which it is constructed. The fulcrum knife-edge is formed on a small block of metal which is driven through a hole in the beam and tightly wedged in it, and it takes bearing on both sides of the beam. The knife-edge at each end is formed in a small rectangular piece of metal slightly tapering, which is driven from side to side through holes in the sides of the oval box, and tightly jammed there. The knife-edge is formed by filing the centre portion of this small block to an edge on which rests the suspension link that carries the load. The knife-edge bearing is the upper side of a hole in the top of the suspension link, properly hardened, and the knife-edge block passes through this hole, so that when once fixed it cannot easily be tampered with or get out of order, and is protected from dirt and rough usage by the oval box, which is a considerable advantage. This is a favourite form of beam, and is very frequently used for inspectors' scale beams.

Scale Beam with Dutch Ends (Plate 1, Figs. 3).

This is an excellent form of beam, and is generally preferred for large balances—say from 2 cwts. to 1 ton capacity—on account of the strength and stability of the end attachments. Both the fulcrum knife-edge and the end knife-edges take bearing on both sides of the beam, and are similarly secured to it.

Grocer's Scale Beam (Plate 1, Figs. 4).

This is a common form of beam, much used by grocers, buttermen, butchers, and others, and in principle is similar to the scale beam with Dutch ends. The

bearings of the knife-edges are generally made of polished agate, and these are fixed in hollow boxes cast in the suspension links; side holes are formed in the boxes to allow the ends of the knife-edges to enter the boxes and drop or be raised into their bearings. This arrangement protects the knife-edges and bearings from dirt and rough usage. The beam is generally of brass, and from the care with which they are constructed these balances are generally very accurate. The scale pan to receive the goods is frequently a porcelain plate, and as it is liable to crack and allow moisture from the goods weighed to soak into it and upset the adjustment of the balance, a hollow brass weight containing loose shot is hung on the weights end of the beam, and by adding or withdrawing shot the balance can be adjusted.

Scale Beams with continuous Knife-edge Bearings (Plate 1, Figs. 5).

In all the scale beams hitherto described the fulcrum knife-edge is driven through the beam and takes bearing on the two sides of the beam, so that the bearing is discontinuous; and in some of the beams the same is the case with the end knife-edges. Practically this amounts to using six knife-edges, and for simplicity and accuracy of bearing it is advantageous to have only three knife-edges, and these with continuous bearing. Various devices have been adopted with this object, three of which are shown in Plate 1, Figs. 5. In No. 1 a hole is cored out of the beam to admit the bearing of the knife-edge. The bearing is carried by a strong pin at the bottom of the suspension link. This pin can be withdrawn in order to place the suspension link round the beam; the bearing is then slid on to the cheeks of the link through the hole, and the pin is then inserted to secure it in place. This arrangement, besides securing continuous bearing for the fulcrum knife-edge, has the advantage of not weakening the beam. In No. 2 a hole is cored out of the beam to admit the bearing, which is contained in the projecting piece at the top of the stand; this arrangement allows the beam to be threaded upon the stand and take up its bearing. Nos. 1 and 2 are used only for small balances. In No. 3 the beam is cut into as shown in order to admit of the bearing being brought up to the knife-edge. This form of beam from its simplicity is frequently used for inspectors' scale beams made to weigh up to 56 lbs.

Bullion Balance (Plate 1, Figs. 6).

This diagram represents a balance of the highest degree of accuracy, constructed to compare standard weights and to weigh bullion up to 1,000 ozs. Troy. It will turn with less than half a grain, or say one-millionth part of the load weighed. The beam is of bronze in a single casting of great depth, cored out in the middle so as to allow the saddle at the top of the stand to pass through the beam and afford a continuous bearing for the fulcrum knife-edge. The knife-edge and its bearing are both of steel and the bearing surface is flat. The end knife-edges also have continuous bearing on flat steel surfaces at the upper part of the suspension links. This is probably the most delicate, as it is the simplest, arrangement for the knife-edges. To relieve the knife-edges from wear when the balance is not being used, a triangular frame is provided, which is lifted and lowered by a cam action at the bottom, and moves vertically in guides fixed on the stand. By its upward movement the tops of the screw studs near its ends are first received by the projecting studs on each side of the suspension links, and the suspension links are lifted off the end knife-edges; and next, as the sliding frame continues its upward motion, the horizontal studs

at the two ends of the beam are received in the forks at the ends of the sliding frame, and by them the fulcrum of the beam is lifted off its bearing. To keep the beam truly in its place, which is very necessary as all the bearings are flat, the recesses for the ends of the screw studs are formed so as to draw the beam without strain into its true position every time that it is thrown out of gear by the sliding frame. The end knife-edges are adjusted and tightly jammed into exact position by means of wedge-pieces and set screws (shown in the end elevation), and the beam is furnished with delicate adjusting weights at its top. The position of the beam with respect to the horizontal is shown by a horizontal pointer (not shown) projecting from one end of it, which plays past a scale, each division of which corresponds to $\frac{1}{10}$ th of a grain. In the end elevation and central cross-section the knife-edges are shaded to distinguish them. The fulcrum knife-edge for a 1,000-oz. balance would be about 4 inches long, and the end knife-edges about 8 inches long.

In another construction the saddle which supports the fulcrum is on the top of a strong vertical shaft which plays in guides in the frame, and is raised and lowered by a cam at the bottom. When the shaft is raised the beam is lifted clear of its supports and is ready for weighing. When it is lowered, the ends of the suspension links are first received on the tops of vertical studs fixed in the frame, which lift the links off their knife-edges; and next, as the shaft continues its downward course, the beam is received on the points of four other vertical studs which hold the beam suspended and relieve the fulcrum knife-edge.

Accelerating Counter-Machine (Plate 1, Figs. 7).

This diagram represents the machine fitted with a goods pan suitable for weighing parcels. The fulcrum knife-edge is lower than the line joining the end knife-edges, and the machine is drawn with the weights pan hard down on its bearings and the beam horizontal. The legs and stays are shown by dotted lines. The stays are in one piece with two shoulders in the middle which thrust against fixed pins in the frame; they are shown in detail in *Figs. 10*. The plan drawing is taken below the scale pans, and the edges of the pans are shown by dotted lines.

Vibrating Counter-Machine (Plate 1, Figs. 8).

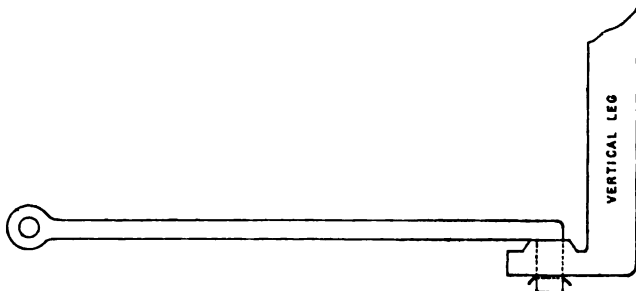
This machine is very similar in its general construction to the Accelerating Counter Machine shown in *Figs. 7*, but the three knife-edges are very nearly in the same straight line, and the position of equilibrium of the beam when adjusted for weighing goods is halfway between the stops, and it sways up and down through the horizontal position like a scale beam. The stays are commonly made as in *Figs. 10*, and work with extremely little friction. These machines are often made very carefully, and various delicate arrangements are introduced, such as the small central adjusting weight on a screwed rod (shown in dotted lines on the plan), and the spring to prevent shocks (shown on the end elevation). The knife-edges often have their bearings in hollow boxes, similar to those shown on the Grocer's Scale Beam (see *Figs. 4*). Machines on this principle are better suited for arriving at the exact weight of a parcel of goods than machines on the accelerating principle, but they are not so rapid in their action

Inverted Counter Machine (Plate 1, Figs. 9).

In this machine the tall side pillars are the vertical legs rigidly attached to the scale pans, and the stays are at the top secured to the ends of a casting carried by the central pillar which is rigidly fastened to the frame. The advantage of long legs has been pointed out on page 20. The beam may be made either accelerating or vibrating; in the *Figs.* it is accelerating, and the beam is drawn horizontal when the left hand or weights pan is hard down on its bearings. The play of the beam is very small, not more than half an inch. This machine is very carefully made, and is such as would be used by butter, cheese, and provision dealers. The stays are usually made as in *Figs. 10*. The dotted lines at the top represent a cap which protects the stays, &c., from dirt, and gives a finished appearance to the machine.

Stays of Counter Machines (Plate 1, Figs. 10).

For the cheaper or rougher kinds of counter machines, and especially when the vertical legs are of considerable length (in which case the stays have very light work, see page 20), the stays are very simply made, as below,

Fig. 17.

being loosely hooked on to the vertical leg and turning on a fixed pin of the frame. But for the more accurate machines, which are generally vibrating machines, the stays are made as in *Figs. 10*. The arrangement appears somewhat singular, and is no doubt the result of experience. There is one stay for the two legs, which is prevented from moving endways in either direction by the two pins (*a a*) in the frame, which however do not prevent it from playing vertically. The attachment to the vertical legs is as follows:—The end (*e*) of the stay passes through a hole in the flat plate (*f*) which is riveted to the vertical leg. The stay is prevented from getting free endways in one direction by its shoulders bearing against the sides (*b b*) of the flat plate, and in the other direction by the piece (*c*) which is riveted to the bottom of the flat plate. The pin (*d*) prevents it from getting free upwards. This arrangement allows of easy movement with very little friction.

Coal Steelyard (Plate 2, Fig. 1).

This is the simplest form of steelyard in common use. It is very roughly made of wrought iron, and cannot be regarded as an accurate weighing-machine.

The power is applied entirely by the sliding poise, which in this example weighed 12 lbs. 1 oz. The arrangement of the knife-edges is strongly "accelerating" in order to overcome the inherent sluggishness of the machine. The knife-edges jammed in their bearing-holes when the long arm of the steelyard was much out of the horizontal, and thus acted as a stop. The steelyard was graduated to weigh up to 1 cwt. by quarters of a cwt., but was capable of weighing more, probably up to 2 cwt.

Roman Steelyard (Plate 2, Fig. 2).

This is a very cheap and convenient machine, and is made to weigh as much as 5 or 6 cwt.; the one figured is made to weigh up to 35 lbs. The power is applied entirely by the sliding poise, which weighs about $1\frac{1}{2}$ lb., and the machine as drawn will weigh from 0 to 8 lbs.; but when turned upside down, and suspended by the inclined hook in the diagram, it will weigh from 8 lbs. to 35 lbs. To do this the link which carries the two hooks revolves round the end of the steelyard, and the hook which is uppermost in the diagram hangs idle; the lower edge of the steelyard (which will then be the upper edge) is graduated to suit the altered arrangement. The leverage proportion is high, being about 22 to 1 when weighing 35 lbs., and the distance between the load knife-edge and the nearest fulcrum knife-edge is only $\frac{1}{2}$ of an inch. It is roughly made and not intended for accurate work, but the upper edge in the diagram could be read to about 1 oz., and the lower edge to about $\frac{1}{2}$ lb. The arrangement of the knife-edges is strongly accelerating; the link of the lower suspension hook is drawn aside to show the vertical pointer.

Steelyard Counter Machine (Plate 2, Figs. 3).

This diagram shows a steelyard mounted on a frame to act as a Counter Machine, and, like other machines which have the pan above the beam, it needs a vertical leg and a stay to keep the pan in equilibrium. It is a convenient machine, especially for weighing out definite quantities of goods, for which purpose definite weights can be hung at the end of the steelyard, and it is much used with a large scoop pan for weighing out potatoes, coal, &c., up to a weight of about 1 cwt.

Steelyard for Testing Materials of Construction.

In the work of Professor W. C. Unwin on the "Testing of Materials of Construction" will be found a drawing and description of a very large steelyard used for a testing-machine. This steelyard has a sliding poise weighing 1 ton with a run of 200 inches. The knife-edges are 20 inches long and $\frac{1}{2}$ inches apart; therefore each movement of 4 inches of the poise exerts an additional pull of 1 ton on the materials under test, and the maximum pull which the poise alone can exert is 50 tons. There is also an end weight of 25 cwt., which hangs at a leverage of 40, and exerts a pull of 50 tons; so that the total pull which the steelyard can exert is 100 tons.

Emery's Testing-Machine.

A testing-machine constructed on a very different principle from that described above is Emery's Testing-Machine, which has been already referred

to on page 12 in connection with the novel construction of the bearings of the levers. It is referred to here only in connection with the measurement of the pressure transmitted to the reducer. This pressure is measured not by one lever, but by a combination of three levers, in which the leverage proportions are 20, 25, and 40 respectively, so that the movement of the end of the last lever is 20,000 times greater than that of the reducer. This gives great facilities for the accurate measurement of the pressure; the weights by which the pressure is actually counterbalanced are applied on the middle lever.

Automatic Machine (Plate 2, Fig. 4).

This diagram shows part of the interior of an automatic weighing machine, such as are found at most railway stations, &c. The weight of the person standing upon the platform is transferred by the levers of an ordinary platform machine to the vertical steel band (a), which is wrapped round an arbor on the axle of the disk wheel (b), to which is rigidly attached the toothed segment (c). The weight (d) is rigidly attached to the axle of the wheel (b), and the counterbalance (e) is hung from the wheel (b) by means of a cord wrapped round it. When the pull of the band (a) comes upon the wheel (b) it revolves through a certain angle in the direction of the arrow until the three forces, viz., the pull of (a), the weight (d), and the counterbalance (e), are in equilibrium. The toothed segment (c) actuates the pinion (f), which carries the finger (g), and this finger remains fixed in position so long as the person is standing on the platform. If now a small weight, as a penny, be passed through the slot (h) it falls into the small box (i), and causes the lever (j) to turn; the lever (j), which turns in friction wheels at (k), and is counterbalanced at (o), carries a toothed segment (l), which actuates a small pinion on the same axle as (f), and free to turn on that axle by a sleeve. This small pinion carries a finger (m), which is arranged to catch against the finger (g) when moved up to it. Consequently as the lever (j) turns, the finger (m) revolves and is stopped when it reaches (g). The sleeve of the pinion which carries (m) also carries the dial finger, and if the dial is properly graduated its finger will indicate the weight of the person. The box (i) has a hinged bottom with a projecting click finger, which as the box descends plays idle over the staves of a ladder arc. When the person steps off the platform, the counterbalance (e) causes the finger (g) to run back to its zero position, carrying with it the finger (m), and causing the click finger of the box (i) to trip open the bottom of the box and let the penny fall out. The lever (j) regains its zero position, and all is ready for another weighing. Since so small a weight as a penny has to move the lever (j) together with the dial finger, &c., it is evident that the workmanship must be good and the friction kept very low by means of friction-wheels.

Platform Machine (Plate 2, Figs. 5).

This is given as a common type of these machines, which differ much in detail though not in principle. It is simple, cheap, and accurate, and the important points referred to on page 47 have been carefully attended to. It is constructed as an accelerating machine, and the upper edge of the steelyard is horizontal when the steelyard is resting on its lower stop. The position of the sliding poise which will just allow the steelyard to rise from the stop gives the weight of the goods on the platform. The leverage of the long body is as 1 to 11, and the maximum leverage of the steelyard is about as 1 to

104, so that the total leverage is nearly as 1 to 112, and 1 lb. at the end of the steelyard balances 1 cwt. on the platform. With the maximum load on the platform these machines are sensitive to about $\frac{1}{2}$ oz., and to very much less when loaded only to one-fourth of their capacity or thereabouts. The accuracy of them will depend upon the care bestowed upon their make and adjustment, but an error of about 1 oz. per cwt. is as much as would generally be allowed. The nut on the top of the short arm of the steelyard is for the fine adjustment, so that the steelyard with the rod, &c., for the loose weights, and with the sliding poise at zero, may exactly balance the weight of the platform, long and short bodies, &c. The four knife-edges which receive the weight of the platform and the load upon it are seen in the plan, and the arrangement of the levers will be readily understood from the plan and sections compared with the diagram and description on page 35, &c. The machine from which the diagram was taken was a 4-cwt. platform machine.

Coal Platform Machine (Plate 2, Figs. 6).

This is given as an example of the great compactness with which a platform machine can be made. The whole machine weighs only 100 lbs., and the outside dimensions are but $11\frac{1}{2}$ inches long by 15 inches broad, and $6\frac{1}{2}$ inches high, with a projection of $7\frac{1}{2}$ inches for the end of the steelyard. It is used for weighing coal into sacks from the truck, and is usually placed on the side flap of the truck when lowered into its horizontal position. From the very limited space available a very compact machine is essential. As will be seen from the diagrams the general principle of the machine is that of the platform machine last described, but the steelyard is returned back over the long body, and when loaded with the proper weight indicates the correct weight of the coal in the sack by its end kicking up. The leverage of the long body is as 6.4 to 1, and that of the steelyard as 7.4 to 1, so that the power is multiplied about forty-seven times, and a weight of $4\frac{1}{2}$ lbs. at the end of the steelyard will balance 2 cwt. on the platform. The platform is carried on the tops of four strong pins, which fit loosely into deep sockets in bosses cast on the under side of the platform; by means of these pins the load is transferred to the long and short bodies. The platform is secured loosely to the frame by a strong bar which passes from side to side through the sides of the frame and through holes in projections cast on the under side of the platform. Thus the platform, though perfectly free to weigh goods, cannot get free from the tops of the pins which carry it. The machine will turn with about $1\frac{1}{2}$ oz., and when weighing up to its full capacity of 2 cwt. might generally be relied on to give the true weight to about $\frac{1}{2}$ oz., or about $\frac{1}{100}$ th part of the load weighed. The steelyard lever is broken off in the plan to avoid complication of lines, but is seen at full length in the section; it is carried on brackets cast with the frame, which are shown in both plan and section.

Skew Lever Weighbridge (Plate 2, Figs. 7).

These diagrams show the arrangement adopted in modern practice for weighbridges of moderate length to weigh up to about 25 tons. The advantage which this form has over the other form of weighbridge, shown in *Figs. 8*, is that all the bearings of the knife-edges are suspended, and that the two levers (the long body and the short body) swing as it were all in a piece when the vehicle to be weighed comes rolling on to the weighbridge; this renders the movement very

free, and diminishes the grind on the knife-edges. The long skew-lever is so arranged in order that the weigh office may be clear of the vehicle while being weighed, and although it looks awkward is found to work well in practice. In the example from which the diagrams were taken the multiplication of the leverage in the long body was about 27 to 1, and in the steelyard was about 17 to 1, so that the total leverage was about 450 to 1. The sections show the suspended bearings; the knife-edges are 6 inches long, so that with the maximum load there would be about 1 ton on the inch.

Truck Weighbridge (Plate 2, Figs. 8).

This diagram shows the older form of weighbridge, which is still largely used and is well adapted for long weighbridges. The two triangular levers of the weighbridge are precisely similar, and take bearing symmetrically on the two sides of the cross-lever, as shown by the enlarged section. The cross-lever pivots on the top of a fixed bracket stand so that the oscillations of the two triangular levers are entirely separated from each other by the cross-lever. The forked end of the cross-lever pulls by means of a rod upon the short arm of the steelyard. In the example from which the diagram was taken the multiplication of the leverage in the triangular levers was 10 to 1, in the cross-lever 5 to 1, and in the steelyard, say 10 to 1, so that the total leverage would be about 500 to 1.

Double Truck Weighbridge (Plate 2, Fig. 9).

This diagram represents the arrangement usually adopted for weighbridges of great length. It is practically a combination of two weighbridges, and there are eight knife-edges to receive the load.

Crane Machine (Plate 2, Fig. 10).

This machine is used to weigh goods as they are hoisted by a crane. The chain is attached to the ring at the top of the machine, and the goods are hung to the hook at the bottom. The sides of the casing which contains the levers are stout wrought-iron plates, and they carry the fulcrum knife-edges of the levers and the suspension ring at top. These machines are made to weigh up to 50 tons or more as required. The one from which the diagram was taken was a 1-ton machine. The multiplication of the leverage was as follows:—In the lowest lever 2 to 1, in the middle lever 5 to 1, and in the top lever or steelyard 8 to 1; altogether 80 to 1. In the Fig. the front side of the casing is removed to show the levers.

Spring Balance (Plate 2, Fig. 11).

This diagram is taken from a dial machine made to weigh up to 7 lbs. The dial plate is $5\frac{1}{2}$ inches in diameter, and the figuring occupies the whole circumference. It is divided to $\frac{1}{2}$ oz. all round; the dial plate and finger are removed to show the springs, &c. The working of the machine will be readily understood from the diagram; the springs are only $1\frac{1}{2}$ inch long, and their full extension is $1\frac{1}{8}$ inch additional. The range of the slide is limited by suitable stops as shown; the slide is made to play vertically without friction at top by means of two pairs of stays, one pair at top and the other at bottom; the stays of each pair are at right angles to each other, and pivot at the ends of protu-

berances cast with the casing; they are partly shown in the diagram. The little central pinion carries a slotted sector piece, to which the dial finger is clamped by screws so as to stand truly at zero when there is no weight in the pan. The machine when in good adjustment would not show an error greater than $\frac{1}{4}$ oz. at any part of the scale.

Mancur's Balance (Plate 2, Fig. 12).

The action of this curious little balance depends upon the elastic extension of a steel rod bent into a circular form, and twisted into loops to receive the suspension hooks, &c. The action of it will be readily understood from the diagram. The scale is attached to the back of the ring, and on the side shown is graduated up to 48 lbs.; but if the load were hung upon the large hook which hangs idle, this hook would by the load be drawn vertically under the point of suspension, and the leverage to bend the steel ring being so much smaller than before, a much greater weight can be measured with the same range on the scale, and for this purpose the other side of the scale is graduated from 0 to 200 lbs. The machine is accurate as far as it goes, and ought to be very permanent in its action, but the range of movement is small, and the uncertainty of the reading would probably amount to $\frac{1}{4}$ lb. on one side and 2 lbs. on the other.

APPENDIX II.

COPY OF CORRESPONDENCE RELATIVE TO A PROPOSAL FOR THE ESTABLISHMENT OF PUBLIC WEIGHING MACHINES FOR THE VERIFICATION OF WEIGHTS OF SMALL PARCELS.

No. 1.

($\frac{H}{ST.}$ 731)

Mr. Airy, C.E., to Board of Trade.

7, Queen Anne's Gate, Westminster, S.W.
10 December, 1878.

SIR,—I have lately been considering the advantages that would attend the establishment of public weighing machines for the verification of the weights of small parcels, and the possibility of constructing and maintaining such machines at a moderate cost, and in a sufficiently durable and accurate form. And I would ask permission to lay my views before the Board of Trade.

It appears to me that if weighing machines could be established in convenient places in the busy parts of London and other towns, so that any person having made a purchase in a shop could immediately, without expense or inconvenience, verify the weight of a parcel at a public weighing machine, it would be impossible for false weights and scales to exist in the neighbourhood of such machines. The certainty of immediate detection would at once cause the suppression of all the false balances. The result would be that the country would be relieved in a great measure from the expense of prosecuting fraudulent dealers, business would proceed with less dispute and wrangling, and the poor would be protected from the shopkeepers.

To ensure a satisfactory result it appears to me essential:—

- (1.) That the machines should be in the public streets accessible to everybody.
- (2.) That the use of the machines should be entirely gratuitous.

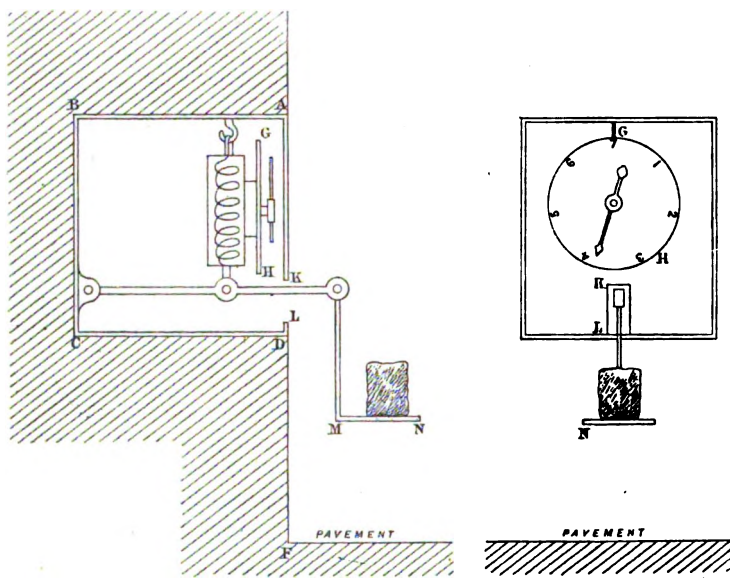
- (3.) That the machines should be simple, easily read, and as little exposed as possible.
- (4.) That the machines should be verified frequently, and adjusted to the requisite degree of accuracy.

For the persons who would chiefly avail themselves of the machines are the poor, who cannot afford to pay fees for verification, and do not like to go inside an office to have the weights of their purchases verified.

I do not think that any difficulty will be found in arranging a suitable machine for the purposes above mentioned; probably the spring balance will be found the most compact and comprehensive form of machine. Such a machine, to weigh parcels, say up to 7 lbs., might be arranged as shown in the diagram.

ABCD is an iron box let into the wall, of which *EF* is the street front. The

Fig. 18.



front part, *AD*, is glazed, so that the dial plate, *GH*, of the spring balance can be seen from the street. The lever-arm of the balance passes through a slot, *KL*, and is received on the snug *L*, at a little over 7 lbs. The scale-pan, *MN*, projects slightly into the street to receive parcels.

I do not wish, however, to advocate any particular form of machine, and it may be thought that a simple balance or steelyard to weigh down at say 1 lb. would be sufficient to act as a check on fraud; and if thought advisable this could be supplemented by other balances to weigh down at say 2 and 5 lbs. respectively. Such machines would be more accurate and less liable to get out of order than a spring balance, but they would be less comprehensive. As in the sketch of the spring-balance machine, the outer scale pan or end of the steelyard would be the only part of the machine accessible to the public.

The foregoing remarks have had reference chiefly to machines adapted for

checking the weight of small parcels, but it is obvious that the same system might be applied, and in my opinion with great public advantage, in checking the weight of heavier articles, such as coals and potatoes. Purchasers are very rarely possessed of machines suitable for checking heavy weights, and there is consequently all the more need for public machines for the purpose.

And I think that the same system could be adopted with advantage at the various post offices, for checking the weight of letters, &c., before posting them. The machines, from their comparatively delicate construction, would need some slight protection from the rain, but they might be perfectly open to the public. The result would certainly be a saving of trouble to the post-office servants, and less annoyance to the public from underpaid letters.

In conclusion, I would remark that a systematic verification of public weighing machines would be essential, for they would certainly be very much used. I do not think that there would be any risk of malicious damage to the machines worth considering. It is well known that the more publicly exposed a machine is the safer it is, and the experience derived from the instruments, clocks, &c., exposed outside the Royal Observatory at Greenwich, the standards of length at Trafalgar Square, and many other instances, goes to prove that the risk of malicious injury would be very slight.—I am, &c.

(Signed) W. AIRY.

The Secretary, Board of Trade.

(^H
^{ST.} 731.)

No. 2.

Board of Trade to Local Government Board.

*Board of Trade (Standards Department),
7, Old Palace Yard, S. W.,
1 January, 1879.*

SIR,—I am directed by the Board of Trade to transmit to you, for the consideration of the Local Government Board, copy of a letter addressed to the Board of Trade by Mr. Airy, C.E., on the subject of weighing-machines for public use.

I am to observe, that if such machines were established, it must be done by the proper local authorities, although the Board of Trade would of course do anything needed in the way of verification of such public weighing-machines.—

I am, &c.

(Signed) C. CECIL TREVOR.

*The Secretary,
Local Government Board, Whitehall.*

No. 3.

(^H
^{ST.} 731.)

Board of Trade to General Post Office.

*Board of Trade (Standards Department),
7, Old Palace Yard, S. W.,
1 January, 1879.*

SIR,—I am directed by the Board of Trade to transmit to you, for the consideration of the Postmaster General, copy of a letter addressed to the Board of Trade by Mr. Airy, C.E., on the subject of weighing-machines for public use.

A similar communication has been made to the Local Government Board, to whom it has been pointed out that if such machines were established it must be done by the proper local authorities, although the Board of Trade would of course do anything needed in the way of verification of such public weighing-machines.—I am, &c.

(Signed)

C. CREIL TREVOR.

*The Secretary, General Post Office,
St. Martin's-le-Grand, E. C.*

No. 4.

(^H_{ST.} 62.) *Local Government Board to Board of Trade.*

*Local Government Board, Whitehall, S. W.,
14 January, 1879.*

SIR,—I am directed by the Local Government Board to acknowledge the receipt of your letter of the 1st instant, and the accompanying copy of a letter which the Board of Trade have received from Mr. W. Airy, C.E., on the subject of weighing-machines for public use.

The Board direct me to state, for the information of the Board of Trade, that it is only where markets have been established by sanitary authorities under the Public Health Act, 1875, that they have power to provide weighing-machines for public use.—I am, &c.

(Signed)

J. F. BOTTON,

Assistant Secretary.

The Secretary, Board of Trade.

[DISCUSSION.

Discussion.

Mr. BERKLEY, President, proposed a cordial vote of thanks to the Mr. Berkley. Author for the great had bestowed in preparing the Paper, which he hoped would give rise to an interesting discussion.

Mr. W. AIRY said he wished to add a few words in explanation Mr. Airy. of one of the diagrams exhibited, which was an enlarged copy of *Fig. 13* in the Paper. It represented the ordinary arrangement of the levers of a platform machine. The long-body lever and the short-body lever were shown, and the load which was upon the platform was received upon the knife-edges of the levers. It was shown in the Paper that if the distance $z_1 x_1$ was exactly equal to the distance $z_2 x_2$, and also if the distance $z_1 t$ was exactly equal to $z_2 y_2$, then the pull on the rod connected with the steelyard would be exactly the same, whether the load came upon the short lever or the long lever. It was therefore immaterial how the load came upon the platform. It might be central, or it might be over one corner, or at one side, but the pull on the rod would always be the same. That was the great principle of platform machines and weigh-bridges, and was essential to the action of the machine. He handed to the President specimens of two or three knife-edges, steel knife-edges and agate knife-edges, such as were used for scale-beams of the most delicate character, made by Mr. Oertling. The skilful way in which the agate was inserted into the metal was worthy of notice.

Professor UNWIN said, although weighing-machines were not at all a specialty of his, there were one or two things in the Paper to which he would first refer. The Author had been good enough to mention his name in connection with a large testing-machine, which he referred to as a type of steelyard on the largest possible scale. He believed that the two first 100-ton testing-machines with a single lever which were made at all were made for him. He had a good deal to do with the general arrangement of those machines, and laid down certain conditions, but with the particular matter which arose on the face of the Paper, viz., the arrangement of the steelyard, he had nothing to do at all. That was due to Mr. Wicksteed, and it was because Mr. Wicksteed had studied the proper conditions of a steelyard for a case of that kind, and had succeeded in making steelyards properly, that he had adopted that type of machine. There were single-lever machines made before Mr. Wicksteed's,

Professor
Unwin.

Professor but Mr. Wicksteed had perceived that in a testing-machine the
Unwin. steelyard was required to be an indifferent lever. In order to secure that, three conditions were necessary. An enormously large and heavy lever was required; also a very large and heavy poise. The lever must indicate instantly the moment when the pull in the specimen exceeded or fell short of a certain limit, and, in order to secure that, three conditions must be fulfilled. In the first place the three knife-edges must be exactly in the same straight line. In the second place, the centre of gravity of the lever itself must be on the same straight line as that which passed through the knife-edges, and in the third place the centre of gravity of the heavy poise weight must also be in the same straight line. Those conditions must be separately fulfilled before they could have a satisfactory steelyard for a testing machine, and it was because Mr. Wicksteed had made a very close approximation to fulfilling those conditions that the machine was very satisfactory as a single-lever machine. He mentioned that specially because he did not like to see his own name referred to in connection with the machine, although he had a good deal to do with the special 100-ton machines, without also mentioning that Mr. Wicksteed had thought out and entirely planned the special steelyard in that machine. The Author had made an exceedingly ingenious and valuable suggestion as to weighing-machines which were to a certain extent to take the place of inspectors of weighing apparatus. The suggestion was altogether admirable, but he doubted whether it was advisable that a spiral spring balance should be used. He might state that he had had a good deal to do with spiral springs, in indicators and other apparatus of that kind. His experience was this: that so long as spiral springs were not tested they were the most comfortable things to work with that they could possibly have, but just in proportion as they began to take trouble in testing their extension carefully, so they began to get a little dissatisfied with them, and at last were driven almost to the conclusion that a spiral spring would never give the same deflection twice for the same load. Of course there was a limit to that, but what he would suggest was that the only possible reason for using a spiral spring balance would be its cheapness. He would suggest to the Author whether it would not be possible, by means of a cylinder of iron in a vessel of mercury, to get an apparatus which would be more reliable. The Author had shown one form of floating balance in his Paper, and he (Professor Unwin) believed that accurate results would be got much better through the pressure of a column of mercury than through a

spiral spring. One other point was this: he had mentioned to the Author that he had a specimen of a peculiar and rather interesting torsion balance which was attempted to be introduced some years ago from America, and he had placed that specimen on the table. It was a very ingenious balance, having the particular merit of requiring no special accuracy of workmanship. The specimen shown was not the most sensitive form, but it was very sensitive; it was borne down with a square inch of ordinary writing-paper very decisively. In that machine there was absolutely no accurate workmanship anywhere necessary. Suppose a simple casting forming the pillar of the machine with a ring of hard steel clock spring round it. A beam attached to a short free portion of the spring tended to take a definite position in which there was no torsion on the clock-spring. Therefore if it moved at all out of that position it showed that the forces acting on the beam were out of balance. The piece of clock-spring acted exactly in the same way as a knife-edge. As long as there was no unequal weight on the two arms of the balance it had a definite position, but the moment there was an unequal weight the balance went out of the definite position to an extent depending on the resistance of the watch-spring to the torsion. A simple piece of clock-spring was substituted for the central knife-edge. In the balance shown there were three frames and two horizontal levers bottom and top. The two end frames merely secured that the beams moved parallel to each other. It should be noted that torsion was only depended on to indicate want of balance. The torsion was not used to measure the weights.

Mr. E. R. DOLBY said it might be of interest to mention a machine with which he had had something to do, and which entirely obviated the necessity for using movable weights upon a steelyard. The diagram, *Fig. 1*, represented the interior of the machine, and the rod *B* was attached at the bottom to the platform of the machine. The lever had a fixed fulcrum *D*, so that when the weight was put upon the platform of the machine, the tendency was to draw the rod *B* down. At the end of the lever there was a rod loosely jointed at *G*, having attached to it a closed iron tube *F*, something like a gas-pipe stopped up at both ends. This tube worked inside another tube *H*, the outer tube being filled with mercury *I*. When the platform of the machine went down, the closed tube descended into the mercury. The weight on the platform of the machine was balanced by the weight of the mercury which was displaced by the part of the tube which sank into it, minus of course the weight of that part of the tube itself. Without

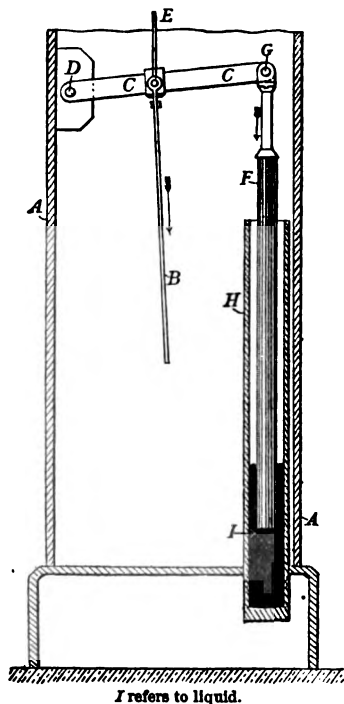
Professor
Unwin.

Mr. Dolby.

Mr. Dolby. entering into details, it was easy to see that the weight of the displaced mercury could be readily

Fig. 1.

Mr. Bartlett.



I refers to liquid.

displaced mercury could be readily made to balance the weight upon the platform. That was the whole of the mechanism for weighing. The point to which he wished to draw particular attention was the very simple method of obtaining the balance without any movable weight.

Mr. C. H. BARTLETT said that for generations past the manufacture of commercial weighing apparatus had unfortunately been carried on pretty much by rule of thumb, and to manufacturers who were anxious to turn out the very best weighing apparatus which could be made, it was a source of great satisfaction to feel that the matter was being now developed and carried on on much more scientific lines. Although perhaps it was not pleasant to say so, it would be difficult to find among the very large number of weighing-machine mechanics, or even amongst some weighing-machine and scale manu-

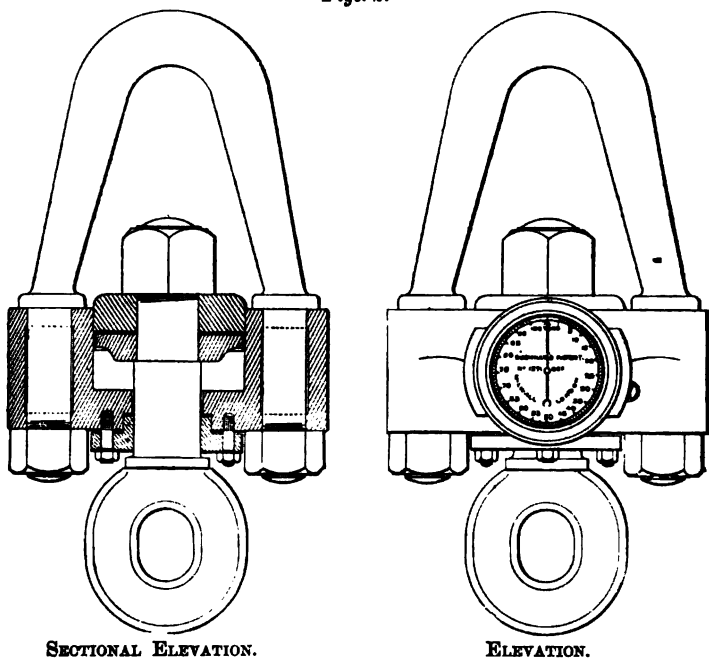
facturers, perhaps more than one here and there, who, although he knew the effect of tilting on a weighing-machine or counter-machine, was able to give an explanation of that effect. They had learned by experience that if they altered the position of this centre, or lengthened that stay, certain results would follow; but what were the forces that produce those results they had no conception, and never thought it worth while to enquire. It was very difficult to get a man who had been in the trade a great many years, who even knew what the centre of gravity was, or the effect of the distribution of metal in levers and beams of different kinds. The manufacturers' principal difficulty with respect to weighing apparatus, since the recent Act relating to Weights and Measures had been passed, was to find out exactly what was wanted in different parts of the country, from the absence of special definite instructions, and he could sympathise with Mr. Chaney in the difficulty of laying down proper regulations for the

inspectors to work by throughout the country, inasmuch as there were no similar rules in existence, as a basis on which to work; and experience had to be bought. A weighing apparatus accepted in London might be discarded somewhere else; on the other hand, what they might send to Liverpool would not do, perhaps, for Birmingham; or what would do for Birmingham would not do at Plymouth. That was the great difficulty that manufacturers had to contend with in endeavouring to send out weighing-machines which would be accurate, and would give, not only the inspectors, but the authorities who governed the inspectors, satisfaction. The idea thrown out by the Author with reference to public weighing apparatus was new to him, and he was almost inclined to agree with Professor Unwin, knowing what he did of spring balances, that if such a practice were carried out it would have to be done on somewhat different lines.

Mr. F. E. DUCKHAM wished to introduce to the members the hydrostatic weighing-machine. Two of these machines were in the room, one of 20 and the other of 5 tons capacity. The machine itself was well known to several members of the Institution. Its construction was shown by *Figs. 2*. It scarcely came within the class of machines used for trade purposes, and therefore some apology might be due for introducing the subject in connection with this Paper. On the other hand, it would be admitted that its type was somewhat unique, and perhaps on that account it might be worth consideration. The machine was constructed with an open top cylinder. A stirrup strap was connected by which it might be suspended from a crane. The cylinder was fitted with a piston, having a piston rod passing downwards and terminating in an attachment for the goods to be weighed. The cylinder was filled with oil or other liquid, in communication with a pressure gauge. When used for weighing goods the machine was simply attached to the crane or sheers by which the goods were being shipped or unloaded. As the goods were lifted by the crane, the whole of their weight was taken by the liquid in the cylinder, and the pressure on the liquid, as indicated by the pressure gauge, gave the weight. The machine had one or two noteworthy advantages. One was that the whole of the weight was taken by the liquid, and therefore there was no wear and tear of knife-edges or other working parts of the machine. It was also exceedingly simple; there were not many working parts, and therefore not much to get out of order. It was compact, light, and portable, for example, a machine capable of weighing up to 10 tons, weighed in itself all complete 90 to 95 lbs., and

Mr. Duckham. occupied a space of about 1 cubic foot. These machines might be used, not only for weighing goods, but also as dynamometers for testing machinery and for indicating strains on roof trusses, or any other structures of that kind. There was no limit to capacity, for if the metal connected with it were sufficiently strong the power might be anything desired. The diagrams represented a very nearly full-sized 100-ton machine. The machine was self-indicating; as the goods were lifted so they were weighed. It acted very much like a swivel link on the crane chain, occupying

Figs. 2.



very little space. In fact, it could be made of a globular pattern so that it would displace an overhauling ball on a crane chain, and do the same thing as well as weigh goods. When the machines were first invented they were made as accurately as possible to certain net areas, and the gauge dials, which were marked off in the first place to lbs. pressure per square inch, were altered to tons on the machine. But that was not found to be satisfactory, nor were the gauges of ordinary commerce found reliable, and gauges of a special type had to be made. These

had a plain dial, which was marked off to indications given by Mr. Duckham. the application of standard tons and cwts. He did not know that any further explanation of the hydrostatic weighing-machine was required, because it might be said to explain itself. He wished to tender his sincere thanks to the Author for the very valuable information contained in the Paper. At the Millwall Docks there were some six hundred or seven hundred weighing-machines of different types, but those machines he had looked upon as mere things that a man outside could put right, and he had taken little interest in them. He could assure the Author that after his Paper, pointing out so clearly the scientific principles which govern the manufacture, adjustment, and maintenance of weighing-machines, he would look upon them much more intelligently in the future than he had done in the past. The Paper, taken as a whole, had been so exceedingly well put together that, although he had tried to do so, he could not find very much to criticise. One little point on page 14 seemed to be a slip of the pen; at all events, it did not agree with his experience, and that was as to the weight which should be brought on the knife-edges. The Author said that with machines of 25 tons capacity, the knife-edge should be in the proportion of 1 ton per inch, so that a machine of 25 tons capacity would have 25 inches of knife-edge. Some years ago he (Mr. Duckham) had a steelyard made of 60 tons capacity; the knife-edges on each side were only $1\frac{1}{2}$ inch, making $3\frac{1}{2}$ inches total length for a 60-ton steelyard. That steelyard had been worked pretty frequently during the last fourteen or fifteen years, and still retained its accuracy and efficiency. On page 50 the Author suggested that the limit of the amount of error which should be allowed in machines should be from one five-hundredth of the load in the case of steelyards to one two-thousandth of the load in the case of scale-beams. That was to say, a beam-scale might be 1 lb. wrong in a ton. Scale-makers would say that they were able to make machines which would, when new, work with much greater accuracy than that, and that the error was very much less than 1 lb. per ton. Sir Frederick Bramwell suggested that he had not mentioned the accuracy of the hydrostatic weighing-machine. The gauge allowed space for about 200 indications, so supposing it to be a 10-ton machine, they could get the two-hundredth part of 10 tons, or say $\frac{1}{2}$ per cent. The machine being free from wear and tear maintained its accuracy, whereas some other machines which had knife-edges, and which professed to weigh much more nearly than this, in course of time gave a much larger percentage of error in their indications.

Professor Herschel. Professor A. S. HERSCHEL said he had had the pleasure of having this Paper in his possession for some time, but he had not had the opportunity of reading it effectually and mastering its contents, as he would like to have done. What he had read of it had convinced him of the great completeness and the exhaustive character of the Paper, which rendered it a very valuable contribution to practical engineering. The question of the sensitiveness of balances had been carefully entered upon, and the Author had shown how far that was affected by practical questions which were not usually taken into consideration.

Mr. Bartlett. Mr. C. H. BARTLETT said that the Paper dealt so exhaustively with the principles on which weighing-apparatus should be constructed to get that perfection in weighing which in some was absolutely essential, and, in all, important, that he felt it was not in his power to enlarge on the principles there laid down—principles which, as he ventured to point out at the last meeting, if they were studied and acted upon, not only by manufacturers, but by the mechanics occupied in such work, would result in the production of a far superior weighing-machine than was found generally in use for trade purposes. Instead of the old rule of thumb ideas, hitherto handed down from father to son, they would have that intelligence and interest displayed which it was the aim of the technical education of the present day to inculcate. The importance of good and accurate weighing-apparatus was, unfortunately, very much underestimated, for it would not be an exaggeration to say, that there were but few commercial transactions in this country that were not directly or indirectly influenced by weight, if to no greater extent than railway- or water-carriage. A weighing-machine was in many respects unlike any other machine, because, whether it was the ponderous weigh-bridge of 50 tons or 100 tons capacity, with all the varying grades down to the assay scale in an air-tight case, it was the last pound, the last ounce, the last part of a grain that had to put the entire apparatus in motion; hence the reason for the reduction of all friction, consistent with durability, to as near nil as possible, conjointly with the closest adherence to those principles of gravity and proper distribution of metal, without which no weighing-machine could be alike accurate with its maximum as its minimum load. The question as to whether for commercial purposes, weighing-apparatus was better constructed on the vibrating or accelerating principle was an open one; each had its advantages and adherents. On the continent the vibrating principle was generally in use, whereas in England until the last

few years, the accelerating principle (except in the case of some Mr. Bartlett. classes of scale beams) was almost universal, but the extensive importation of cheap counter-balances of French make was largely responsible for the creation of a demand for a vibrating balance—a demand which was now being met by the manufacturers at home. Those remarks applied in the main to counter weighing-apparatus; for heavy machines the accelerating principle held its own, and although there were some weighing-machines and weighing-bridges manufactured in this country on the vibrating principle, they were a very small percentage of the whole. The question of the amount of error allowable in a weighing-machine used for trade was one that required very careful consideration, and while the system adopted by the Board of Trade in the model regulations of dividing them into classes, was, in some respects, open to objection, he scarcely thought with Mr. Airy that the difficulty would be got over by the adoption of one class for each kind of weighing-apparatus, or that to insist on a high standard of accuracy was not necessary. As Mr. Airy pointed out, the main object of the inspection of trade balances was the protection of the public; but a very large and important section of the public were the users of balances—the shopkeepers themselves, and for their protection the enforcement of a fairly high standard of excellence was of vital importance. These people, it should be remembered, purchased in bulk with one draught of the scale, and retailed out the same quantity into, perhaps, a hundred or more parcels, with the result that during the process the fair and legitimate profit a shopkeeper fancied himself getting was oftentimes a sham, with an inferior balance, and not the least of the causes that helped to bring small shopkeepers to grief. Inspectors of weights and measures would agree with him when he said that ignorance of the evil consequences to themselves of using inferior and sluggish weighing-instruments prevailed to an extraordinary extent amongst that class of people; and if the purchaser wanted protection from short weight, the seller equally required that protection, which would ensure his being supplied with a balance that would not compel him to give overweight—that it was what it was represented to be, and fitted for his special purpose. For that reason he thought it was of great importance that certain classes of scales should be marked Class I, and that Class I should be a guarantee for good quality. To a large extent, of course, people must look after their own interests. The meaning of Classes I, II, and III might not for a time be understood by certain sections of the trading public, but the fact of the existence

Mr. Bartlett. of those classes would quickly educate them to the fact that a Class I scale meant that with proper care 1 lb. of tea would weigh out into 16 ozs., and that it was greatly to their advantage to use the most accurate and sensitive balances they could get. It was unfortunate the Board of Trade had left it to the Local Authority to determine the amount of error admissible; there could not possibly be any reason why that should not be defined, and the absence of uniformity on that point, as the Author pointed out, led to much confusion. The Author, on p. 51 of his Paper, said that a large proportion of the small shopkeepers in crowded towns were disposed to practise petty frauds. If such was the case—it was not a very pleasant reflection—he should like to feel that the really dishonestly disposed were but a small minority, and by far the majority were anxious to give an ounce for an ounce and a pound for a pound, neither more nor less. Although such an arrangement was condemned by the majority of inspectors, he felt that within a certain limit, defined by the capacity of the instrument, some method should be allowed for keeping the scale in even balance. At present considerable difficulty arose from the fact that the only way of adjusting the differences arising from cleansing the pans, chipping the china plates, absorption of moisture, &c., was to scrape or file those fittings of the scale which might be the heaviest—a very objectionable practice, especially when carried out by amateurs on an extensive scale. The patent vibrating balance, No. 8 in the drawings, was one of his own designing. The screw running diagonally across the beam was about 5 inches long, with a fine thread, and the adjusting power from end to end of the travel was about six drams. It could only be used with a special key, but the arrangement, although sanctioned by the Board of Trade, was, notwithstanding, objected to by some inspectors without, he thought, any valid reason; but this discrepancy was a further proof of the necessity for fixed and definite instructions on which all authorities and inspectors might act. To hold the office of Inspector of Weights and Measures, and to carry out conscientiously the duties involved in that office, was no sinecure. Unfortunately, too many local authorities looked upon the inspection of weights and measures as a troublesome obligation, and a work that ought and must be made to pay. The importance of the subject was underrated, and the technical knowledge necessary to make a competent inspector underestimated; and, as a consequence, inspectors were in many districts underpaid, and had to fulfil arduous and important duties at a great disadvantage. The Government, in passing the

Weights and Measures Act, were strongly against centralization, Mr. Bartlett. and for that reason left it to each Local Authority to make its own by-laws for the carrying out of the Act, subject always to the approval of the Board of Trade, the model regulations serving as a basis. There were grave doubts as to the wisdom of this course. A pound weight in London was a pound weight in Glasgow, Dublin, Liverpool, or Plymouth; the same applied to a bushel measure of capacity or a yard measure of length. That being so, was there any reason why the apparatus or instrument that would measure accurately an equivalent for a pound in London should not do the same in Liverpool, Glasgow, or anywhere else? The weights and measures of this country were as absolutely fixed quantities as the values of our coinage; and, being so, there was no reason why the apparatus used to determine their equivalents should not be constructed on defined and uniform principles, which should hold good all over the kingdom, and be beyond dispute; instead of which the most diverse opinions existed as to what was essential in a good weighing-instrument, resulting in a great deal of confusion and worry to users, and expense and trouble to manufacturers. Many reasons might be urged why, instead of the present system, inspectors should be Government officers under travelling district superintendents, who would, of course, be tried practical men. Such a system would free them from many of the difficulties of their present position. The lines agreed upon between the chief of the department and his half-dozen lieutenants, would speedily bring about uniformity all over the kingdom, and that on the most satisfactory basis. The inspector would be freed from the difficult and invidious task of having in many cases to test and condemn as unfit for use the weighing-instruments of individual members of his city, or County Council, or perhaps of his own committee. He would be free also from anxiety as to the financial results of his labours, and not the least advantage and satisfaction to him would be that, instead of being responsible to a committee of gentlemen, who had sundry and variable opinions of their own, he would be responsible to a chief inspector of sound practical experience. Without wishing to condemn as unworkable the substitute for inspectors proposed by the Author, there were to his mind serious objections to it, and it was questionable if any court of law would convict on any evidence of short weight which rested on a test made some time and distance from the place of purchase, during which interval an unsealed packet might be tampered with, to the detriment of the seller. He might say in conclusion that, although the

Mr. Bartlett. recent Act relating to weights and measures was a very valuable one, and in its results must be beneficial to the commercial community, the detail of its working, and the method by which its provisions were enforced, left much to be desired. It should be the aim of inspectors to assist each other as much as possible in the correct reading and interpretation of the Act; to exchange opinions with others who perchance might have a larger experience than themselves; to become thoroughly acquainted with the broad principles governing the construction of weighing-machinery, and which were so ably laid down by the Paper; and also to remember that, while it was the aim of the Legislature, in passing the Weights and Measures Act, to promote honesty and justice in trading, it was well to read between the lines, and so interpret its spirit and intention, that the right-thinking portion of the public might see it was greatly to their advantage to second and co-operate with the efforts of inspectors in their endeavours to carry out its provisions.

Mr. Spencer. **Mr. ALFRED SPENCER** said the Paper was valuable to local authorities in many ways; it was useful to the inspectors as indicating clearly the principles applying to the details of construction of various weighing-machines, which was a very necessary part of an inspector's education. He knew no other Paper in which the principles, were laid down so clearly and so distinctly as in that of the Author. One question upon which the Author touched, and one that was very important for local authorities and inspectors, was the amount of allowance of error, and for sensitiveness in various types of machines. The question of allowance of error raised a larger question, which had been mentioned by the previous speaker—namely, that of uniformity in the application of laws as to weights and measures and weighing-machines throughout the country. He fully agreed that the present system, which allowed all local authorities to make their own regulations, and fix their own allowances of error, was very inadequate for the well-being of the country and the trade. The fact was that makers, inspectors, tradesmen, and the public, were all placed at great practical disadvantage in connection with the administration of the Weights and Measures Acts, from the fact that, in various parts of the country, in adjoining districts and neighbouring towns, there were great differences in the allowances for error. It was true that certain allowances were indicated in the model regulations issued by the Board of Trade, but each Local Authority put its own interpretation upon them. The consequence was that both the trade and the public were at a loss to know what allowances

of error were really recognized. That difficulty could be met in Mr. Spencer. a very simple and easy way. Instead of the regulations being made, as at present, by the Local Authorities, and therefore varying in different parts of the country, they should be made by the Board of Trade, who had competent advisers of far greater experience than any Local Authority could possibly have. He hoped the Act would be altered in that direction. If the Government, by means of an order in Council, which could, of course, be amended from time to time as new inventions were brought forward, should lay down precisely, or as nearly so as possible, what the allowances for error in various types of machines should be, the trade and the inspectors would have no difficulty in the practical administration of the Act. The same argument applied with almost equal force in other directions, and he was strongly of opinion, having had the supervision of the administration of the Weights and Measures Acts in London for the last few years, that it would be altogether a better plan for the Government to issue general regulations. Some of the practical effects of the want of uniformity were constantly brought before inspectors. If a Local Authority endeavoured to work up to a high standard, the effect was to drive machines, which should be tested in their own district, into an adjoining district where the standard was much lower, and they might find themselves flooded with machines of inferior type, stamped elsewhere, and having an allowance of error far beyond that which they could approve. The Paper was particularly valuable to inspectors, as it pointed out in a scientific manner, and at the same time in a very clear way, the various effects upon machines caused by alteration of level and other circumstances. The only point in the Paper which he desired to criticise was the view taken by the Author on the question of inspection. The Author proposed on p. 51, as an alternative to the present system, that public weighing-instruments should be fixed at various places and should be available to the public at large, and that the duties of an inspector should be confined to verifying those weighing-machines from time to time. He presumed that the Author meant that the public themselves should have the means available for testing the accuracy of the weight of the goods they bought. As a practical man he saw the greatest possible difficulties in the way of a scheme of that sort being successfully adopted in this country. He need hardly say that on the method of using a weighing-machine depended in a very large measure the accuracy of the weighing, and he could not imagine that those machines, open for the use of the

Mr. Spencer. public at large, could by any possibility be kept in accurate condition, or would be properly used. The Author also advocated that these machines might properly be spring balances, and he spoke throughout the Paper of spring balances in such a manner as to encourage their use, on the ground of simplicity, cheapness, and efficacy; but the experience of inspectors was that spring balances were probably the most inaccurate and unreliable form of all weighing-instruments. Every variation of temperature affected their accuracy, and they were specially liable to get out of order. He also agreed with the last speaker that the vibrating form of weighing-machine was far more reliable, and far more suitable for the ordinary uses of trade than any form of accelerating machine, and he should be very glad to see the English public and the English trade come round to the practice, which was in force on the continent, of adopting, in preference to the accelerating machine, some form of the vibrating machine.

Mr. Dodson. Mr. H. C. DODSON said there were one or two observations that he wished to offer. One was with regard to "Classes" of machines, whether instruments should be divided into "Classes," or whether they should not. On looking at the allowances of errors, which were estimated at fractions of the loads, it seemed that one class scarcely sufficed for all instruments. For instance for the ordinary 56 lbs. counter machine, the allowance of error was one-thousandth part of the load; that would mean that the total error would be a little more than 14 drams. If that were to be the uniform error of allowance for all ordinary counter-machines of like capacity, and there was only to be one class, then there would be no distinction between the allowance of error for a machine which a dealer in coal would use and for a machine which a tobacconist would use, or some tradesman buying and selling a much more expensive article. The allowance of 14 drams on a 56-lb. machine, if it were used in the wholesale tobacco trade, would be a very fair allowance, but for a coal machine that error would be exceedingly small, and it would necessitate very poor people purchasing very high-class machines which would not answer their purpose, inasmuch as they would very soon get out of order, on account of the high standard of accuracy which would be required. It therefore appeared to be necessary to divide machines into classes. It would be difficult to suggest off-hand what the classes should be, but he was distinctly of opinion that machines used for weighing rough material—iron, coal, rags and cheaper things—principally by poor people, should have a larger allowance of error than machines used for weighing

more costly articles. He scarcely thought there would be any danger as to the respective classes of machines becoming interchanged, and so used for purposes for which they were not intended, because a person buying or selling costly articles would certainly not use a machine which might show a large amount of error; on the other hand, a poor person using a machine for rough work would not require one to turn with such a fine degree of accuracy. He thought the use of spring balances in trade might facilitate fraud. A small balance of 7 or 8 lbs. might easily be read $\frac{1}{2}$ an ounce against the purchaser if the dial hand was not very accurate and very close to the figure. On the other hand, with a large spring balance weighing 400 or 500 lbs., in many cases it was only necessary to pull the spring out to its greatest extent by weighing the maximum load, to cause the machine to vary at least 1 lb. or more at once. He had sometimes seen variations of 4 lbs., 5 lbs., and as much as 10 lbs., after once pulling out the spring to its fullest extent, and then putting on a light load. He certainly agreed with the Author that the domiciliary visits of inspectors were most objectionable, and every inspector would thoroughly endorse that view. On the other hand it was very difficult to see how public weighing-machines could be established in order to do away with domiciliary visits. If such a system were to come to pass there would have to be in the crowded parts of London, at all events, very many machines, and the difficulty of attending them would be very great. If the poor wished to weigh their goods, there would probably be a dozen or more people waiting at one machine, and there would have to be so many machines, of so many sizes, in order to meet special requirements.

Mr. THOMAS KYLE said he was an inspector, and had read the Paper very carefully. It was a unique work of its kind, and was a valuable addition to their scanty information. There were two or three points on which he would like to say a few words. The Author had spoken of the convenience of spring balance weighing-machines. They were certainly convenient so long as they were correct, but he did not consider that the life of a spring weighing-machine in ordinary everyday use would much exceed eighteen months or two years. The Author also said that they were cheap. The first cost was not always the criterion of cheapness. After eighteen months the spring would have to be re-arranged, repaired, and the machine would have, in the majority of cases, to be sent to the makers. The weighing-machines of the present day, with the exception of spring weighing-machines, were con-

Mr. Kyle. structured upon the lever principle. It was here, he considered, that there was room for great improvement. In the American torsion balance machine they had torsion fulcrums in place of knife-edges and bearings. If members would approach this question impartially, and with an open mind, he was sure they would be rewarded. He had recently tested a counter weighing-machine made by one of the leading makers and passed by an inspector. Placing the weight upon the extreme edges of the pan, which the trade considered unfair, and knowing the weak points of counter weighing-machines, he found by moving the weights that the readings showed a variation to the extent of 7 ozs. Surely it would not be admitted that they had reached the height of perfection when the reading of the counter weighing-machine of 14 lbs. would show such a variation. At present, there was a great want of uniformity, which, however, should not be placed at the door of the Board of Trade, or of the model regulations, but at the door of the scale-makers, who, with the exception of some six or seven leading firms, manufactured scales as close to the limits allowed by the regulations as possible, and in place of a scale being able to pass in London, Bristol, Liverpool, or any place else, they now find that half-a-dozen inspectors have half-a-dozen different notions of the same scale. He would therefore impress upon scale-makers the advisability of aiming at making a good article, and then there would be no complaints as to want of uniformity as at present.

Mr. Chater. Mr. J. CHATER regretted that the Author had confined his attention so much, and that the remarks had been so largely directed to one phase only of the question, namely, the consideration of small weighing-machines. Such machines were, of course, of the greatest importance to the multitude, but it would have been of very much greater interest, not only to some makers who were present, but also to many gentlemen in the profession, if the Author had devoted more of his Paper to the consideration of the larger machines with which so many members of the Institution had to deal. The question of working weighbridges, say from 10 to 100 tons, brought into consideration very many important matters which were well worthy the attention of the members. The very name of a large weighing-machine was suggestive of considerations worthy of careful study; for it was called a "weighbridge," and the desideratum involved in its construction was the possible combination of the qualities of a perfect bridge, with the capabilities of a perfect weighing-instrument. Inasmuch as a weighbridge rested upon four knife-

edges, which were necessarily made free to swing or oscillate to Mr. Chater. their lowest and quiescent position, and was at the same moment subjected not only to the dead weight of a large locomotive, but also to the backward thrust of the revolving wheels, as well as to the alternating side thrusts of the wheel flanges, the whole of which adverse strains have to be borne by the delicate knife-edges, it would be obvious that the construction of such a complex machine was a matter calling for the utmost care, and one in which experience would still be the best guide.

Mr. LYON SAMPSON said he wished to speak on the subject of Mr. Sampson. mechanical construction. Speaking of knife-edges, the Author compared the friction to a journal in a bearing. That was hardly correct. It was more a rolling friction, because the knife-edge never fitted a bearing so closely as to have to rub upon it. The Author, at page 26, pointed out, as an advantage of the loose-weight system over the sliding-poise, that the weight carried by the fulcrum of the steelyard was less with the loose weights than with the sliding-poise. If the machine was fully loaded, of course it could make no difference whether there were several loose weights at the end of the steelyard or one solid weight. With the intermediate weights of course the weight would be a little less on the centre of the steelyard; but, as they had to be made sufficient to carry the full weight, that could matter little. He thought the Author did not condemn the accelerating machine as it ought to have been condemned. A weighing-machine ought to give only one result; but, of course, with accelerating machines they got two results. If they placed a less weight on the steelyard than the balance of weight on the platform and moved it forward till the steelyard dropped, it had one weight; but if they put a greater weight on the steelyard, and moved it till the steelyard rose, a different result was obtained, and in some cases there was a very wide difference between the two.

Correspondence.

Mr. W. B. AVERY thought that there was such a paucity of Mr. Avery. literature on the subject in this country that a lucid demonstration of the theory and properties of familiar types of weighing apparatus was specially welcome, and that the contribution could not fail to be instructive to interested persons, and particularly to inspectors of weights and measures. But he would prefer to tender his comments, not in the form of a criticism of the technical portion of the Paper, but rather by way of endorsing and supplementing the

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Mr. Avery. Author's views on the subject of the administration of the law which now controlled and regulated the use of weighing-instruments. From the nature of his business associations he was, unfortunately, placed in possession of exceptional information as regarded the anomalies, contradictions, and abuses which were the consequences of an entire absence of any statutory provision for ensuring uniformity of procedure in carrying out the official inspection of scales and balances. The "accelerating" and "vibrating" principles, as applied to weighing machinery (to which the Author had given close attention in his admirable Paper), were fruitful sources of disagreement among inspectors. In one district it might happen that none but "vibrating" scales and machines were allowed to be used; while in another, and possibly neighbouring district, those made on the "accelerating" principle were lawful; the result was the discomfiture of the unfortunate maker and purchaser of weighing-apparatus, who, in their ignorance of the prejudices and idiosyncrasies of every individual inspector in the kingdom, were powerless to avoid the pitfalls which officialism placed in their path. Personally, he had little hope of an improved condition of things until Parliament should authorize the issue of uniform regulations—not permissive merely, but compulsory—by a department of the State to which final reference could be made by manufacturers, inspectors, and the general public. In order to deal effectively with a subject in which so many technical considerations were involved, a permanent scientific commission would appear to be a paramount necessity. The constitution of such a commission, and its objects, were set out in a little work entitled "Suggestions for the Amendment of the Law relating to Weights and Measures," published by his firm in 1888. It was therein submitted that a permanent commission, which would possess the confidence of the public, might be readily formed of gentlemen of scientific attainments who were officers of the Board of Trade, with the addition of one or two scientific experts; provided always that no member of the commission should be a manufacturer of weighing-apparatus. From this commission it was proposed that instructions should proceed from time to time as to features which should be ever present in the construction of all weighing-apparatus for use in purchase and sale. Any novel weighing-appliance was to be submitted to the commission for examination, and, if so far approved, be open to the inspection of the public at the Board of Trade for a stated period. If within such period any substantial defect were declared to exist, it should be notified by the objector to the commission in writing, and the commission would eventually

decide whether the instrument should or should not become lawful **Mr. Avery.** in this country. If declared lawful, the commission would grant a certificate to that effect, and neither maker nor user could be harassed by any inspector so long as the instrument in question was in good repair. The Author had justly spoken of the duties of the inspector as in many cases difficult and invidious, and requiring the exercise of considerable tact and ability in their performance. He would, in addition, point out that under existing conditions, the inspector was exposed to serious temptations through the nature of his relationship to his employers. The County Councils and other local authorities looked to the fees to amply recoup them for the expense of maintaining their weights and measures departments; if, indeed, they do not expect a substantial addition to their revenue from this source. The conscientious inspector who refused to stamp worthless scales had his labour for his pains, for no fees would thereby accrue; while, by straining somewhat the liberal discretion which the law and his local authorities allowed him, he might be tempted to extensively stamp scales of which his better judgment would disapprove, and thereby show a handsome return of fees, to the probable improvement of his own position and prospects. The appointment of travelling inspectors, which he had long advocated, appeared to provide the only possible safeguard against the danger to which he had referred. In omitting any direct reference to the technical portion of the Paper, he trusted it might not be attributed to any lack of appreciation on his part, or be supposed that he was indifferent to what is after all the primary consideration, viz., the construction of weighing-apparatus on sound scientific principles; but as the operation of the law bearing upon such apparatus in its present unsatisfactory state was likely to check rather than to promote improvements in construction, he had preferred on the present occasion to confine himself to the economical rather than to the scientific bearings of the subject. In conclusion, he would express the hope that any remedial legislation upon this important question which might occupy the attention of Parliament at some future time, would receive the valuable support and influence of the Institution of Civil Engineers.

Mr. E. A. COWPER said that, in 1854, his friend **Mr. George Mr. Cowper.** **Makins** made a very delicate balance for assay purposes, particularly for a weight of 12 grains in each scale, and such was the delicacy of the balance that it would weigh to $\frac{1}{1,000}$ grain, and, indeed, a less weight could be appreciated. The total length of the beam was 10 inches, and its weight 103 grains. It was, of

Mr. Cowper. course, an open-work girder, but it was more particularly the centre and end bearings that he wished to draw attention to, as they were peculiar at the time they were made. The ends of the beam were forked, and each arm received a screw with a hard steel point, it being secured by two nuts in the beam. A piece of cornelian, with a slight hollow in it, rested at one end, on one point, whilst a slight groove in the other end of the cornelian rested on the other point, and the hook for the pan-chains depended from the middle of the cornelian. Thus there were the smallest possible amounts of surface in contact, and the least possible friction.

Mr. Elliot. Mr. THOMAS ELLIOT felt much indebted to the Author for his exhaustive Paper, from an inspector's point of view. He thought that general traders' weighing should be a more correct process than it is, and to this end, that the use of "accelerating" instruments should be discouraged. They were certainly convenient, but unsatisfactory, because first, equilibrium was practically never obtained with them, therefore a "draft" was allowed for or against the purchaser (almost exclusively the latter), and this multiplied by thousands of weighings was considerable; secondly, they varied so much more than "vibrating" instruments when tilted out of position. In compound-lever machines, those that were "vibrating" were, he considered, the better by far, especially such as were constructed with the loose rocking-pieces, mentioned on p. 46 of the Paper, so as to provide for the platform to swing in two directions. This prevented lateral friction upon the knife-edge, while a load is being rolled on, and secures a uniformity of suspension. He also thought that sliding counterpoises, providing for balance of the whole of the load, were far preferable to the use of loose proportional weights. He was of opinion that, in a very large majority of retail shops, weighing would be much more satisfactory if traders would use one good vibrating machine instead of three or four cheap accelerating machines, as was now so common, and that machines of all kinds ought to be more frequently cleaned and taken more care of than now in many instances, and that devices to obviate cleaning of bearings should be distinctly discouraged. He thought that the description of one result of tilting platform-machines (pp. 43, 44) was hardly accurate; a steelyard could not properly be said to change its character from "vibrating" to "accelerating" simply on change of position. On p. 36 the Author said: "If the knife-edges be arranged . . . the steelyard will always be 'accelerating,'" &c., and he held this to be the true definition. In most of the instances referred to, the defect would be

seen at once upon moving the sliding-poise one notch beyond zero ; Mr. Elliot. then a "vibrating" steelyard would descend on to the lower stop, but an "accelerating" steelyard would require, perhaps, many notches of advance to hold it down, and *vice versa* as to the opposite position. The question of a level base for platform-machines was no doubt very important, and great care was taken by makers to secure a truly level bed for them, but the use of a spirit-level upon the platform was unsatisfactory, because no casting as it leaves the mould was true, and platforms for weighing-machines were seldom or never planed. The true method was to level the machine by means of straight edges resting on the knife-edges before the platform was placed in position ; any test after the machine was fixed was best accomplished by testing with standard weights upon various parts of the platform. The Author had but a passing reference (p. 47) to disengaging-gear in compound-lever machines, and he submitted that this was a highly important point. Unless a machine was truly level and very carefully adjusted, the relieving gear would cause considerable trouble, for it was no uncommon thing when a platform was loaded, and the bearings then relieved by the gear, to find no two readings on the steelyard alike as the operation was repeated. Some makers held that it was better to have no disengaging-gear whatever, and to prefer the quicker blunting of the knife-edges to the daily recurring errors in weighing which such gearing involved. The question of the level of small compound-lever machines was a very difficult one. Many were made to run upon wheels, and to any one who was familiar with the floors of London shops and warehouses, it was often a matter of great doubt as to whether accurate weighing was ever attained with such machines. He thought that some provision for ascertaining and adjusting the level of these machines ought to be embodied in each machine, and to form a condition of their use. Spring balances he held to be very unsatisfactory instruments. Springs were, practically, far less reliable than levers for weighing ; changes of temperature affect them considerably, by reason chiefly of the great degree of expansion and contraction, in consequence of the great length of metal in one piece affected. The requisite compensatory devices for counteracting variations increase the cost as well as the complication of the machine, so that a good spring balance was as expensive as a lever instrument. The only point in their favour was portability, but this sometimes operated prejudicially by the neglect which it begot. He believed that their use in ordinary trading was decreasing. He could not agree with the Author in his observations (p. 50) on "total error." He considered that the sensitive-

Mr. Elliot. ness of a machine was a vital point in trading. The weight necessary to turn a scale represented the quantity of goods which a seller must either give to or take from the purchaser distinct from the actual weight indicated, and this repeated thousands of times was necessarily important. The other sources of "total error" mentioned by the Author, viz., inequality of leverage, inequality of balance, pans of unequal weight, and machine generally out of adjustment, were faults so patent that no machine could be approved which possessed them in an appreciable degree. But the error for sensitiveness must always exist appreciably, and in a well-made machine he thought that the total error consisted chiefly of this element, and, therefore, the question as to the amount of error to be allowed for sensitiveness was one of considerable moment. He thought that a much smaller amount should be allowed for sensitiveness error than had been the custom hitherto. He did not agree with the Author in his observations (pp. 51, 52) upon the existing system of inspection. Without touching upon the proposal for public weighing-machines, he would say that his experience was contrary to the Author's conclusions. He found that, in an overwhelming proportion, the visits of the inspector were appreciated and valued by traders, who were mostly very courteous, and often told him that they looked upon such visits as a guarantee for themselves that their weighing-instruments, &c., were in proper order, and that they courted inspection. This applied, of course, only to the cases of honourable traders; to others, he submitted, it was necessary and desirable that the inspectors' visits should be "unpleasant and objectionable."

Mr. Loewen-
herz.

Mr. LEOPOLD LOEWENHERZ said that there were several points in connection with the Author's Paper to which he wished to draw attention. In the first place, he could not quite agree with the Author's complaint as to the want of literature on the details of weighing-machines. He knew, for instance, a book by Professor E. Brauer,¹ "The Construction of the Weighing-Machine, &c.," accompanied by an atlas, which in this respect more especially contained a very great amount of information; he would also mention the illustrations of weighing apparatus published by the Imperial Normal Weights and Measures Commission of the German Empire (Kaiserliche Normal Aichungs Kommission des Deutschen Reiches), (Text and Atlas; Berlin, 1884, W. Moeser.) Finally, a small work by Dr. Francis Place,² "Theory and Construction of

¹ "Die Konstruktion der Waage u.s.w." Weimar, 1880; Bernhard Friedrich Voigt.

² "Theorie und Konstruktion der Neigungswaage." Weimar, 1869.

the Bent Lever," might be named. The classification of weighing-machines, given on page 3 of the Paper, appeared to him not sufficiently exhaustive. It led the Author to treat the balance with fixed counterweight as a special form of the unequal-armed balance (p. 25). Although this had many advantages for the purposes of theoretical investigation, still he thought that it was just the balance with fixed counterweight balance which represented the most general case, in so far as by means of it the mass of a body, after being connected with another body of any shape suspended and free to turn, could be measured by the displacement of the centre of gravity thereby produced. All other lever balances, equal-armed and unequal-armed, might in this sense be regarded as more specialized arrangements, inasmuch as with them the displacement of the centre of gravity, produced by the body to be weighed, was neutralized, either entirely or within a certain amount, by the use under particular conditions of counter-weights. Further, he could not entirely share the Author's favourable view of spring-balances (*vide* p. 48). According to experience obtained in Germany the elasticity of the usual springs was subject to considerable alterations in consequence of changes of temperature, and of the shocks which were unavoidable in ordinary life. On this account such balances were not allowed in commerce (in Germany); they were only employed as domestic weighing-machines; it was true that the postal and railway service they were allowed as luggage and parcel weighing-machines, but were being gradually superseded by the equally exact and rapid but more uniform bent lever balances. He missed, in the Author's Paper, the weighing-machines with automatic registration, which were extensively used in Germany, and which weighed and registered continuously grain and mealy materials. He hoped at some future time to be able to discuss more fully than was at present possible the Author's excellent Paper.

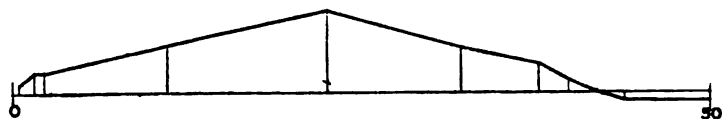
Mr. H. H. P. POWLES sent the results of an experiment with a commercial spring balance, which he thought might be of interest. The spring balance was one of the ordinary kind constructed to weigh 30 lbs. by ounces, and was provided with a graduated dial and index, each revolution of the index corresponding to a load of 10 lbs., so that the index made three complete revolutions for 30 lbs. There were two similar spiral springs connected with a cross-bar which extended as the load was put on, and the motion was communicated to the index by means of a rack and pinion. In order to try the accuracy of the balance a dial about 13 inches

Mr. Loewen-herz.

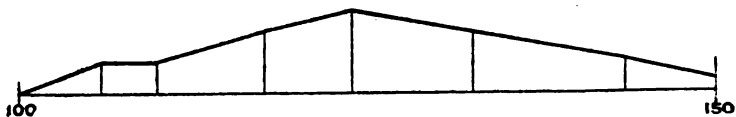
Mr. Powles.

Mr. Powles. in diameter, graduated to $\frac{1}{100}$ ths and a long index, were provided, and readings were taken from 30 grams up to 13,600 grams. The

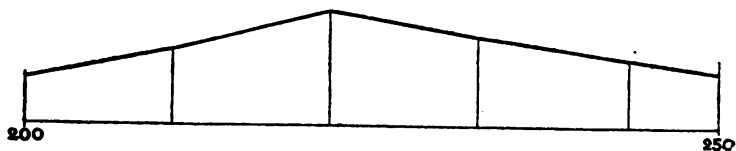
Figs. 3.



1ST REVOLUTION OF INDEX ON DIAL.



2ND REVOLUTION OF INDEX ON DIAL.



3RD REVOLUTION OF INDEX ON DIAL.



The vertical height of the curve above or below the horizontal lines gives the difference between the readings by the dial and the true weight, to a scale of 70 grams to 1 inch.

position of the index was noted both on adding and taking off weights, and in no case did the readings taken with increasing

load differ more than 0·2 of one division of the scale from those Mr. Powles taken with decreasing load, this difference corresponding to a maximum of 9 grams or about $\frac{1}{4}$ oz. avoirdupois. The appended Table gave the results: column 1 gave the weight on the balance, column 2 the reading on the dial, column 3 the weight corrected to the reading, column 4 the difference between the actual weight on the balance and the corrected weight, column 5 the error per cent. of the load on the balance. It would be seen that the error

Weight on Balance in Grams.	Reading on Dial.	Weight Corrected to Reading.	Difference.	Error in Percen- tage of Load.
30	0·75	34·01	+ 4·01	13·33
80	1·95	88·45	+ 8·45	10·55
100	2·40	108·86	+ 8·86	8·86
500	11·40	517·09	+ 17·09	3·42
1,000	22·70	1,029·65	+ 29·65	2·96
1,500	33·37	1,515·00	+ 15·00	1·00
2,000	44·00	1,995·80	- 4·20	0·40
2,500	55·00	2,494·70	- 5·30	0·21
3,000	65·70	2,980·88	- 19·12	0·64
4,000	87·85	3,984·78	- 15·22	0·38
4,500	99·20	4,499·61	- 0·39	..
5,000	110·50	5,012·17	+ 12·17	0·24
5,600	124·10	5,629·05	+ 29·05	0·51
6,000	132·80	6,023·67	+ 23·67	0·39
6,500	143·60	6,513·55	+ 13·55	0·20
7,000	154·30	6,998·89	- 1·11	0·01
7,500	165·10	7,488·77	- 11·23	0·15
8,000	176·00	7,983·18	- 16·82	0·21
8,500	187·20	8,491·20	- 8·80	0·10
9,000	198·80	9,017·40	+ 17·40	0·19
9,500	210·10	9,529·90	+ 29·90	0·31
10,000	221·40	10,043·48	+ 43·48	0·43
10,500	232·25	10,534·62	+ 34·62	0·33
11,000	243·10	11,026·77	+ 26·77	0·24
11,500	253·90	11,516·64	+ 16·64	0·14
12,000	264·25	11,986·11	- 13·89	0·12
12,500	275·10	12,478·26	- 21·74	0·17
13,000	286·17	12,981·74	- 18·26	0·14
13,500	297·50	13,494·30	- 5·70	..
13,600	300·00	13,607·70	+ 7·70	..

in percentage of the load was small for any load above 2,000 grams, and that the error varied from excess to deficiency. The diagram showed that these variations occurred at certain places in the revolution of the index. This was clearly shown on the diagram, and pointed to inaccuracy in the rack and pinion used for giving motion to the index. The diagram represented the actual errors in weight from column 3 of the Table, the horizontal line representing the graduations on the dial for the three revolutions of the index. It would be noticed that the line of error crossed the

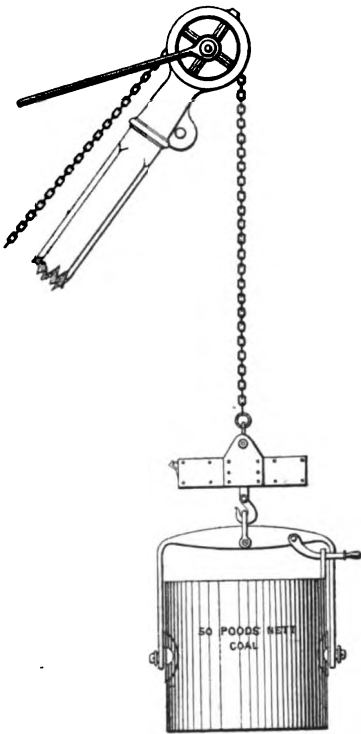
Mr. Powles. horizontal line at very nearly regular distances at 50, 100, 150, 200, 250 and 300. The mechanism of the balance being very rough, it seemed that in all probability the errors were in the mechanism and not necessarily in the springs. By graduating the dial to the load a very large percentage of the error would be removed.

The balance experimented with makes no pretence to accuracy, but was a sample of a kind of which hundreds were in use, and had been for a great number of years; and had been used from time to time on a rope friction brake for testing a gas-engine at the Electrical Standarding, Testing, and Training Institution, Faraday House, Charing Cross Road.

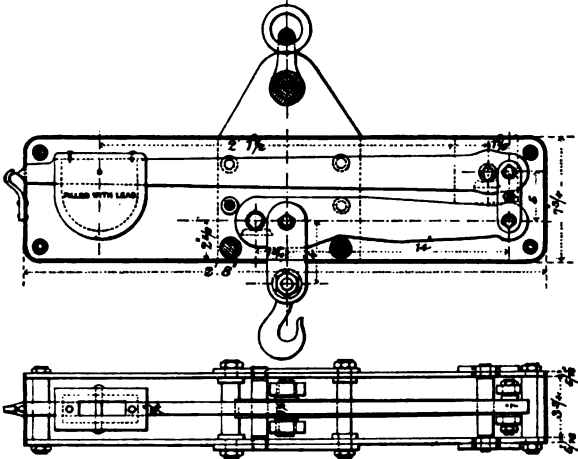
There was no doubt that spring-balances made with more accurate indicating-gear than the one in question would be a most convenient form of weighing-machine for practical purposes, as they read direct without requiring addition of weights or any adjustment, and were durable.

Mr. THOMAS URQUHART said that he had occasion sixteen years ago, as Locomotive Superintendent of the Grasi-Tsaritsin Railway, Russia, to devise a simple efficient and expeditious means of weighing and loading tenders with coal, and designed the simple double lever dynamometer, as figured below, for a fixed weight of coal of 50 poods = 1,805 lbs. English, or including the weight of the iron tub (18 poods = 650 lbs. English), making a total weight on the dynamometer of 2,455 lbs. English. The dynamometer, as would be seen by the *Figs. 4 and 5*, was composed of two main plates held parallel together by columns, so as to give the necessary amount of rigidity as a foundation. The fulcrum knife-edges of the two levers rested upon hardened steel dies, which were tightly pressed into holes formed in the two main plates. As the centre of gravity line intersected the points of suspension the dynamometer had no tendency to cant. The lower lever had a proportion of 1 to 9, the upper lever a proportion of 1 to 17, therefore the weight necessary on the end of the upper lever in order to balance 68 poods = 2,455 lbs., neglecting the weight of the levers themselves, would be = $\frac{2,455 \times 1.75 \times 1.5}{15.75 \times 25.5} = 16.04$ lbs. This weight was formed by running melted lead into a hollow casting. The whole mechanism was boxed in by sheet-iron to prevent the weather affecting its sensitive action, and also to prevent its being tampered with. For nine years while burning coal, before the introduction in 1883 of liquid fuel on the Grasi-Tsaritsin Railway, these dynamometers gave every satisfaction. This system of coaling

Fig. 4.



Figs. 5.



Mr. Urquhart. tenders, in which these dynamometers played the most important part, commended itself for three reasons. First, the weight of fuel given to each driver was exactly correct and certified by the driver himself; Second, the rapidity of coaling was all that was wished for, as the tubs were filled between trains before the engine came into the coaling yard; Third, the system of fixed weight of 50 poods of coal was very convenient, as the drivers were obliged to sign their demand for a quantity divisible by 50, thus simplifying the keeping of accounts. It might be stated that when a tub was full of coal the centre of gravity was above the trunnions, and on releasing a hook the tub tipped over completely, and emptied itself. When the tub was empty the centre of gravity was under the trunnions' line, thus making each tub self-righting.

Mr. Airy. Mr. W. AIRY, in reply, remarked that several of the speakers seemed to disapprove of spring balances, and had compared them unfavourably with knife-edge machines for durability and accuracy. He had not said that they were so accurate, nor did he think so. But for ascertaining the weight of a given article or parcel they were more rapid and convenient than knife-edge balances, and were in general quite accurate enough for most trade purposes. He thought that the experiments of Mr. Powles were very instructive, both as to the degree of accuracy and as to the cause of the errors; the results of these experiments agreed well with experiments of his own on various spring balances. Professor Unwin and Mr. Dolby had advocated mercury balances as preferable to spring balances. He did not, however, think that they would be an improvement; for they would require rack and pinion work (or some equivalent mechanism) to actuate the index as much as the spring balances, and as he had stated in the Paper, and as Mr. Powles had shown, the chief errors in spring balances were those due to the rack and pinion work. Neither would the mercury balances obviate the errors due to expansion, for the mercury would be more affected by expansion than springs. So far as he had been able to judge, the springs behaved with remarkable uniformity, and the errors of the machine could be reduced to a very small amount by improving the workmanship. Several gentlemen had referred to his suggestion of substituting one class for the existing three classes of the various trade weighing-machines, and had very fairly stated the objections which they saw to his proposal. He admitted that there were difficulties which might require much consideration, but ventured to think that, in expressing the errors as part of the load, in taking the whole error instead of the sensitiveness error only, and

in reducing the number of classes, he had suggested the direction Mr. Airy. in which improvements might be effected. With regard to his suggestion of public weighing-machines as a means of preventing fraud he thought that one or two of the speakers who criticised it had not quite understood it. Of course he did not suppose that if a buyer found by means of a public weighing-machine that a dealer had given him short weight an action at law could be maintained. But for preventing fraud this would be wholly unnecessary, as the buyer, having found that the dealer had given him short weight, would not deal with him again, and thus a fraudulent dealer would lose custom. As to the machines getting out of order the very essence of the scheme was that the inspectors of weights and measures should constantly inspect and adjust them and keep them in proper order. He believed that there would not be found the smallest difficulty in working the scheme proposed, and that if efficiently worked it would absolutely stamp out fraud, so far as weights and measures were concerned, without ever an inspector going into a shop. Some of the speakers thought that "accelerating" machines should be forbidden by law, and none but "vibrating" machines allowed. He did not agree with these gentlemen. The accelerating machines were very useful and had advantages of their own, as was abundantly shown in the Paper, and only needed to be rightly used. But unquestionably in cases where it was impossible to ensure their being kept level, as in the case of costermongers' barrows, vibrating machines would be more properly employed. Mr. Loewenherz had very properly pointed out that German books treating of the details of weighing-machines had been published. But these works had not been translated into English, or were not generally available in England. Mr. Duckham's hydrostatic weighing-machine evidently had great advantages as a crane machine. It seemed to be quite accurate enough for checking the weight of heavy loads, and in simplicity and compactness left nothing to be desired. The crane weighing-machine, described by Mr. Urquhart, was similar in principle to the one shown in Fig. 10, Plate 2, adapted to weigh a fixed load. Mr. Chater seemed to think that weighbridges had been neglected in the Paper. This was hardly the case, as several forms of weighbridges had been figured and described. But in point of fact there was not much to be said about weighbridges. They were, or ought to be, absolutely level, so that none of the errors due to dislevelling would come in, and in constructive detail they had been perfected to a wonderful degree. Mr. Elliot's remarks on platform machines seemed to be sound and instructive. Probably no

Mr. Airy. one was better acquainted with the anomalies and inconveniences of the existing system of inspection of weighing-machines, as affected by the different views and instructions of different local authorities, than Mr. W. B. Avery, and his remarks on this subject, and his suggestion as to the manner in which an improvement could be effected had evidently been well weighed, and were worthy of careful consideration. Mr. E. A. Cowper had described a delicate balance in which the scale-pans were carried on pins instead of knife-edges. This method was in common use for very small balances, and was very suitable for such machines. In conclusion, he desired to express his pleasure at the useful and practical tone of the discussion.

19 January, 1892.

No meeting, in consequence of the death of H.R.H. the Duke of Clarence and Avondale, Hon. M. Inst. C.E.

26 January, 1892.

GEORGE BERKLEY, President,
in the Chair.

The President communicated to the meeting the action taken by the Council in regard to the death of the Duke of Clarence and Avondale, K.G., Honorary Member, and, at his suggestion, that action was approved and adopted by the members present in solemn silence, all standing, and ordered to be recorded.

Moved by Mr. Berkley, President, seconded by Sir Benjamin Baker, K.C.M.G., Vice-President, and

Resolved, That the Council desires to offer respectful sympathy to their Royal Highnesses the Prince and Princess of Wales in the loss they have sustained by the death of their eldest son, under extremely sad circumstances, and to express the earnest hope that strength and fortitude may be extended to their Royal Highnesses and to the other members of the Royal Family in this great affliction.

The above minute having been forwarded to Sir Francis Knollys, K.C.M.G., C.B., for submission to H.R.H. the Prince of Wales, elicited the following reply :—

“SANDRINGHAM, 3rd February, 1892-

“Sir Francis Knollys is desired to convey to the Council and Members of The Institution of Civil Engineers the sincere thanks of the Prince and Princess of Wales for the sympathy they have expressed on the occasion of their Royal Highnesses' bereavement.”

The discussion on the Paper on “Weighing-Machines” occupied the evening.

2 February, 1892.

GEORGE BERKLEY, President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

WILLIAM NEWBY COLAM.
CHARLES ARTHUR FRIEND.

FREDERICK TALBOT JOYCE.
ARTHUR SMITH TRUMAN.

Also that the following Candidates had been admitted as

Students.

JOHN HALLEN ABBOTT ABBOTT.
RICHARD JOHN ADDISCOTT.
ARTHUR ALAN ASHWORTH, B.A.
JOSEPH NICHOLSON BEATTY.
LOUIS GEOFFREY BUCKNELL, B.E.
WILLIAM FRANCIS HENRY CREBER.
SIMON SILVER DAVSON.
FRANCIS CRESSWELL FFORDE.
BALDWIN FRANKLAND.
JOHN RIBTON GORE.
FRANCIS REGINALD HULL.
BERNARD HURT.
ERNEST LYON.

JOHN ALISTER McDONNELL, B.A.
IAN DUNCAN MACKENZIE.
CHARLES BERESFORD NICHOLLS.
PHILIP PEDLEY.
GEORGE FRANCIS PITTAR.
JOHN NEWTON SHEFFIELD.
ROBERT HOLBOYD SLADE.
THOMAS SMITH, B.E.
HUGH WORTHINGTON STATHAM.
CHARLES CONSTANT VERNET.
CHARLES FORDYCE WHEELER, B.A.
FREDERIC DICKINSON WORKMAN.

The following Candidates were balloted for and duly elected as

A Member.

OTHNIEL FOSTER NICHOLS.

Associate Members.

JOHN SIDNEY ALFORD, Stud. Inst.
C.E.
ALBERT EVERSHED ANTHONY.
WALTER FRANCIS BAYLEY.
PETER BOSWELL BROWN, Stud. Inst.
C.E.
HENRY BRUCE.
GEORGE HANNYNGTON COLE-BAKER,
B.A., Stud. Inst. C.E.
JAMES FOYELL LOVELOCK CROSLAND.

EDWARD KEVILLE DIXON, M.E.
JOHN EBBES.
AMBROSE EMERSON, Jun., Stud. Inst.
C.E.
WILLIAM BEAN FARR.
ALFRED ROBERT FINCH.
WILLIAM DICKINS GIBBINS.
GEORGE LEOPOLD GREGGSON, Stud. Inst.
C.E.
THOMAS FRANCIS HARVEY, A.K.C.

Associate Members—continued.

SYDNEY SANDERSON HAWKINS.	ALEXANDRE PORTELLA PASSOS.
THOMAS WILLIAM HORN, JUN.	CHARLES NEWTON RUSSELL.
EDWARD HUNT.	EDWARD BALLARD SAVAGE.
HENRY BENTLEY JAMESON, Stud. Inst. C.E.	GEORGE HALL SCOTT.
HARRY HUNT PEVERIL LE MESURIER, Stud. Inst. C.E.	SYDNEY FRANCIS STAPLES, Stud. Inst. C.E.
LOUIS MARTINEAU, Stud. Inst. C.E.	WILLIAM PERCY STEANE.
JOHN WILLIAM METCALF.	THOMAS TOMLINSON.
RICHARD HENRY MIDDLETON.	WILLIAM UNSWORTH.
ARTHUR HENRY MORGAN.	REGINALD WISSENDEN.
LEONARD JOHN NEWMARCH, Stud. Inst. C.E.	CHARLES HENRY WORDINGHAM, A.K.C., Stud. Inst. C.E.
	WILLIAM ADOLPHE WORSOE.

(*Paper No. 2561.*)

“Gold-Quartz Reduction.”

By ALFRED HARPER CURTIS, B.A. (Lond.), F.G.S., Assoc. M. Inst. C.E.

IN this Paper the Author proposes to deal with the principal crushing and pulverizing machines and processes employed in the reduction of gold-quartz. The expression “Gold-Quartz” will include all auriferous siliceous rocks, from true quartz to siliceous conglomerates such as the “banket” of Witwatersrand, independently of the condition of mechanical mixture or chemical combination in which the gold content of such rocks occurs. Many of the machines about to be described are equally applicable to the crushing or pulverizing of other ores.

It will be conducive to a thorough appreciation of the principles which should underlie the construction of gold-quartz reduction machinery, if some prior reference is made to the manner in which gold occurs in auriferous rocks. Gold is found in siliceous veins and other deposits in three distinct conditions, namely:—

(a) “Free” or “Native”—that is to say, metallic, but alloyed almost invariably with a small percentage of silver, copper, iron, or some other metal. Quartzes carrying the bulk of their gold-content in this simple form are technically termed free-milling ores, owing to the fact that the precious metal can be separated from adhering, or containing, gangue or matrix, by first crushing the ore to a certain degree of fineness—indicated by the size of the disseminated gold—and then subjecting the pulp or the powder (according as the crushing has been a “wet” or a “dry” process) to the action of mercury, which, forming an amalgam with the gold, separates it from the valueless gangue. “Free

[THE INST. C.E. VOL. CVIII.]

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gold" may occur in sufficient size to be visible by the naked eye, or disseminated throughout its matrix in such a finely-divided condition as to be invisible except under microscopic examination, or when concentrated. The forms in which free gold occurs are numerous, including octahedral and dodecahedral crystals (rare), thin plates, threads, branch-like aggregations, small irregular masses, coarse grains, and fine specks.

(b) *In association with metallic sulphides, sulph-arsenides, etc.,* such as iron and copper pyrites, mispickel (arsenical iron pyrites), zinc-blende, and sulphides of antimony and bismuth, almost certainly in a state of mechanical mixture. Sulphides of iron and copper carrying gold are known as "auriferous pyrites," the term pyrites being frequently applied also to other auriferous sulphides and sulph-arsenides, which are also technically known as "sulphurets."

(c) *In chemical combination with another substance,* as with tellurium, in the minerals graphio tellurium, or sylvanite, and foliated tellurium, or nagyagite, these constituting true "ores."

For the sake of brevity, the word "ore" will in this Paper be used of all siliceous gold-containing rocks, irrespective of the precise condition in which the gold occurs.

OUTLINE OF PRINCIPAL MECHANICAL PROCESSES OF GOLD EXTRACTION.

(a) *Free-milling Ores containing no significant percentage of Pyrites or other Refractory Compounds.*—The ore is broken by heavy hammers at the mine into lumps of convenient size for tramming to the dressing-mill, where, if necessary, it is further broken into pieces sufficiently small to pass into the jaws of a Blake or other ore-crusher. On leaving this machine, the coarsely crushed ore is generally fed—automatically or by shovel—into the "mortar-box" of a stamp mill in which one or more steel-shod "stamps," or "stampers," worked by water, steam, or electric power, gradually reduce it to a fine pulp or to a powder, according as the stamping is done by a wet or a dry method. In the former case, water is introduced into the mortar in carefully regulated quantity, the pulp produced by the pulverising of the ore being ejected, when sufficiently finely comminuted, by splashing through the meshes of a wire screen, or the perforations of a stamped grating. The size of these meshes or perforations should be determined by and varied with the fineness or coarseness of the gold disseminated through the ore under treatment.

The auriferous pulp on its ejection from the mortar is generally

allowed to run slowly over a series of slightly inclined copper plates, the clean surfaces of which have been previously amalgamated with mercury. This mercury absorbs and forms an amalgam with a large percentage of the gold contained in the pulp, the remainder being caught on rough blankets or hides, or more completely separated from the valueless sand by concentration with "Vanners" or other machines. At intervals of a week or more the auriferous amalgam is scraped off the surface of the copper plates, the excess of mercury is squeezed out through chamois leather or canvas, and the residue of stiff amalgam is retorted to distil off the mercury. The resulting "retorted gold" is melted, and is then ready for the refiners. In the case of dry-stamping, the pulverised ore is exhausted from the mortar by a fan or some other aspirating contrivance, there being several methods of subsequently concentrating the ore and separating the gold. In the case of free-milling ores, more than half the gold saved by amalgamation is caught on copper plates fitted inside the mortar.

Instead of stamps numerous other contrivances, the most important of which are rolls and roller mills, have come into some considerable use as pulverizers of gold-quartz after its passage through the ore-crusher.

(b) *Pyritic Ores*.—These may carry a percentage of free gold in addition to auriferous sulphurets; and the latter may be in small or in excessive quantity. Should the percentage of pyrites be comparatively small, it is usual to extract the free gold by the amalgamation process, and to concentrate the pyritiferous tailings. The gold is extracted from these concentrates either by grinding and amalgamation with mercury in "pans," or by roasting them and treating the product with potassium cyanide, chlorine, or some other chemical solvent. In certain exceptional cases, smelting may be the most convenient method of treating such concentrates. Should the percentage of pyrites be, on the other hand, large, the amalgamation process will fail to separate the free gold of the ore, owing to the "sickening" of the mercury; and the pyrites is, in such cases, generally concentrated without any previous separation of the free gold. Certain pyritic ores are occasionally subjected to very careful roasting before fine comminution, and are then treated by the free-milling process; but, for reasons into which the Author cannot now enter, the results of such roasting operations are almost invariably unsatisfactory.

It would be impossible to enumerate the ore-crushers and pulverizers which have, more especially during recent years, been

brought into public notice. The number of successful contrivances is, however, by no means considerable; and it will be necessary to describe in detail only a comparatively small number of machines.

1. ORE-CRUSHERS, OR STONE-BREAKERS.

(a) *Machines on the Reciprocating-Jaw principle.*—These appear to have been first brought into practical use by Mr. Eli Whitney Blake, of New Haven, Connecticut, the original machine being designed to break up trap-rock for macadamizing roads. The business of such a crusher at a gold mill is to break up lumps of quartz, on their arrival from the mine, into pieces of small size suitable for further reduction by stamps or other fine pulverizers. Since the expiration of the Blake patent, various improvements have been made in the machine, which is now manufactured by a large number of English and American firms. One of the best-known forms of these improved machines is the stone-breaker and ore-crusher shown in Fig. 1, the construction and action of which must be so familiar to civil engineers as scarcely to require any explanation. The machine makes 250 revolutions per minute; and at every revolution the eccentric on the shaft, F, causes the movable jaw, D, to advance about $\frac{1}{2}$ inch towards the stationary jaw, C¹. Hence, if lumps of quartz be dropped between the jaws, they will be broken by the next succeeding bite, and the fragments will then fall lower down and get broken again, until they are small enough to pass out at the bottom. The distance between the jaws at the bottom limits the size of the fragments, and this distance may be regulated at will, either by turning the nut of the wedge, L, or by substituting for either or both of the toggle-plates, J and K, others that are longer or shorter. The crusher is made in several sizes, ranging from a machine whose dimensions at the mouth are 10 inches by 8 inches, with an approximate product per hour of 4 tons 3 cwt., to a size convenient for stamps or other fine pulverizers, up to one whose mouth is 30 inches by 24 inches, and whose stated product per hour is as much as 23 tons 2 cwt. 3 HP. (nominal) is required for driving the former machine, the latter requiring 20 HP.

Fig. 2 shows a more recent variety of jaw crusher, known as the Lever-motion Stone and Ore Crusher,¹ which differs in many

¹ The makers are the successors of Mr. H. B. Marsden, Leeds.

details from the form just referred to, motion being given to the crushing jaw, D, from a crank-shaft, F, which is substituted for the eccentric-shaft of the machine represented in Fig. 1.

In the Dodge crusher (Fig. 3), an important modification of the Blake, the reciprocating jaw is pivoted at its lower end, so that the movement of the jaw is greatest at the top and least at its lowest point—exactly the reverse of the Blake swinging-jaw. As a consequence, the product dropping from the Dodge crusher is of more nearly uniform size. It will also be seen that, the size of the product being regulated by the distance the jaws are set apart, and there being little or no motion at the lowest point of the movable jaw, a finer product is obtainable with a Dodge crusher than with a Blake, at, however, the cost of a certain amount of “capacity.” The Dodge crusher is more particularly recommended for fine-crushing in concentration-works.

The efficiency of well-constructed jaw crushers has been so amply demonstrated by their work in all mining countries, that it is scarcely necessary to enter at any length into a theoretical discussion of their merits. Speaking generally, it may be stated that the principal objections attending their use are, first, that the jaw does effective work only during its forward stroke; secondly, that thin flat pieces of rock may at times pass the jaw without being broken; and, thirdly, that the product leaving the machines is of various and not uniform sizes. The first of these objections is the only one which applies with any force against the use of jaw crushers as first reducers of gold quartz; and as the absolute capacity of such crushers per hour is so large, even this defect is of little importance. In the gyratory crushers about to be described, an attempt has been made to obviate some of the faults of the Blake machine; but it will be readily seen that objections which might be serious in the case of a machine intended for the breaking of rock for road metalling—where a produce of more or less uniform size is essential—do not apply to rock-breakers intended only for a preliminary coarse crushing of gold-quartz.

(b) *Gyratory Crushers*.—This classification includes the “Comet Crusher” and the “Gates Rock and Ore Breaker”—vertical gyratory crushers, which closely resemble each other in construction. A brief consideration of the principle of these machines, which are perhaps hardly so well known in this country as the Blake crusher, will show that the reciprocating-jaw principle is reproduced here in a disguised form.

Fig. 4 is a sectional perspective view of the Gates rock and ore breaker, the following particulars of which are in the main

abstracted from the maker's description :—An upright spindle, G, of forged steel, is supported on a chilled iron octagonal step, P, and at the upper end is held in the centre of the crushing-chamber or shell, Q, by the top piece, C. Immediately below this top piece a chilled iron breaking-head, F, is fitted on the vertical shaft in such a way that it cannot turn on it. The crushing face of the head, F, is made fluted or plain according to requirements, and tapers towards the top of the shaft; the downward-tapering shell, Q, in which it works, is fitted on the inside with twelve chilled-iron liners, E. There are three openings in the top of the machine through which the material to be broken is fed all round the head. A gyratory motion is imparted to the shaft, G, by the brass eccentric box, D, which is securely attached to the bevel wheel, L, forming a long boss to it. This eccentric box is babitted on the inside and outside of the thickest part, as shown by the heavy black lines, the wear being all on that side. The outside of the eccentric box is turned to fit the bottom plate, in which it revolves; while the inside is bored to fit the journal of the shaft, G, with enough eccentricity to throw out the shaft sufficiently to produce a breaking of the rock between the head and the shell. The shaft, G, is a loose fit in the eccentric box, D, and only rotates when there is no material between the breaking-head and the liners. Any revolution that occurs in such case is due to the slight friction of the eccentric box in its motion around the journal of the shaft.

The closest point of contact between the breaking-head and the liners—that is to say, the point at which the rock is broken—is always at that part of the head which is opposite the thickest part of the revolving eccentric-box, the point of contact constantly moving round with the eccentric; so that, when the eccentric-box has made a complete revolution around the shaft, the point of contact has moved to every point around the liners, E. When the head has been moved to the point of contact opposite, the crushed material drops a little, to be further comminuted when the head returns to that point. When the rock is broken sufficiently small it drops on to the inclined diaphragm, or shoot, covering the bevel gearing, and passes out through an opening in the shell, QQ. At the end of every revolution of the eccentric-box, the breaking-head has done duty on every piece of rock in the crushing chamber; and there is not a moment when it is not breaking the rock at some point. It will be observed that only a small line of crushing surface, from top to bottom of the head and liners, comes into contact at one instant with the rock under treatment. As the

breaking-head does not revolve when crushing, there is no grinding action in the chamber.

A Gates machine, whose capacity is from 2 to 4 tons (of 2,000 lbs.) per hour—according to the character of the rock under treatment—requires about 4 I.H.P. for the breaking, elevating, and screening of compact gold quartz; while the largest size has a stated capacity of from 100 to 150 tons per hour, and requires about 150 HP. for the purposes mentioned. Owing to the circular form of the breaking-head, flat pieces of rock cannot by any chance fall through uncrushed. The diameter of the head, and consequently the area of breaking surface, increases towards the discharge end, so that the material as it is broken has increasing space in which to spread itself out, and this results in finer crushing than is practicable with an ordinary Blake machine, whose width of breaking surface is the same at top and bottom of the jaw.

Gyratory crushers are extensively used in the United States and elsewhere, as many as two thousand of the Gates variety being stated to be now at work breaking road-metal, concrete, cement-stuffs, iron-slugs, quartz, and ores of various kinds, with satisfactory results. In this country, where the jaw crusher is far more frequently used, considerable prejudice exists against the Gates breaker. The machine is somewhat complicated in construction, and its precise action is not always readily understood. The wearing parts have, however, great durability; and the Author knows no instance in which the machine has in practice failed to give satisfaction, the principal objection urged by its actual employers being its comparatively large first cost.

2. CRUSHING ROLLS.

The term "rolls" is taken to include only those machines in which crushing is effected by and between the surfaces of a pair of revolving cylinders—that is to say, crushers of the "Cornish" type and improved forms thereof. "Roller" and "Edge-runner" mills will be treated as a distinct class.

(a) *Cornish Rolls*.—It is unnecessary to describe at any length the construction of these primitive machines, which cannot compete with stone-breakers for the preliminary treatment of gold quartz, because of their comparatively small capacity and little durability. They consist of a pair of cast-iron cylindrical shells, of unequal

length, and about 3 inches in thickness, fixed by wooden wedges on to cores or bosses keyed on geared horizontal shafts. The plummer-blocks supporting the shorter roll are movable, and can slide between parallel guides, the rolls being compressed by weighted levers, whose shorter arms bear against the movable plummer-blocks.

(b) *Improved Cornish Rolls*.—An important modification of the older rolls consists in the substitution of adjustable steel buffer springs, or india-rubber buffer cushions for the clumsy lever-and-weight arrangement. The shells of the rolls are made of more durable metal, but the shafts are still geared. As coarse crushers they possess many merits; but, in the modern gold-quartz mill, such work is more economically and effectively done by jaw or gyratory crushers.

(c) *Krom's Improved Steel Crushing-Rollers*.—These rollers deserve special mention, both on account of their excellent construction and because of their claim to be used with great advantage for pulverizing gold quartz to any necessary degree of fineness. The several improvements upon Cornish rolls embodied in Krom's machine may be summarized as follows:—

1. The crushing tires are made of forged steel, and are firmly and simply secured to the shafts by cone-shaped heads;
2. Belt-pulleys are substituted for tooth gearing, which enables the rolls to be run at any desirable speed, thereby increasing their capacity;
3. The adoption of swinging pillow-blocks;
4. The crushing strain is taken up by bolts, on which powerful springs are mounted;
5. There is a special form of hopper for spreading the ore evenly across the face of the rolls. The importance of this point will be obvious;
6. The rolls are enclosed in a housing.

Figs. 5 and 6 are side and end views respectively of the latest form of Krom's swinging-block steel crushing-rollers, and Fig. 7 is a perspective sketch of the complete arrangement. In Fig. 5 the hopper is shown broken off towards its middle, while in Fig. 6 it is altogether removed.

A very important consideration in determining the value of rolls as fine pulverizers is the manner in which the crushing-shells, or tires, wear, and their durability. It is stated by users of the Krom rollers—which claim to be essentially fine pulverizers—that the faces of the tires wear evenly, and do not become grooved, and that they have a long “life,” the reasons being as follows:—

(a) They are forged from best open-hearth steel ;

(b) The ore fed into the hopper is previously reduced, by a fine-crushing Blake or other breaker, to a considerably smaller size than is usual with Cornish and other rolls, the average size of the pieces admitted into the hopper not exceeding that of a small broad-bean ;

(c) The ore is spread evenly over the face of the rolls by the special form of hopper, the feeding being in all cases automatic.

The life of the rolls is, moreover, prolonged by their being, in general, arranged in double sets—one pair receiving the bean-sized ore from the breakers, the other “finishing,” or finely pulverizing the screened coarser produce of the first pair. In the case of most gold quartzes two pairs of rolls are generally found to be sufficient; for some ores, however, in which the gold is disseminated in an unusually fine condition, as many as three sets are sometimes employed. As an indication of the durability of the tires of these rolls, an instance occurring among statistics in the Author’s possession may be quoted. At the Bertrand Mining Company’s Lixiviation Mill, Nevada, where Krom’s rolls are used instead of stamps for pulverizing silver ores with a quartz gangue, 15,000 tons of ore were crushed before it was found necessary to put new tires on the finishing-rolls; while, after a further crushing of 5,000 tons of ore, the tires of the roughing-rolls were still expected to be good for two or three months’ work. In neither case were the tires found to be at all grooved, the reason for their renewal being that they had become worn too thin for further work. The rolls in the Bertrand Mill are stated to crush 50 tons of hard quartzose ore in twelve hours, to pass through a 16-mesh screen; while in the Mount Cory Mill, Nevada, 50 tons are reduced to 30-mesh in the same time. For silver ore, where care has to be taken that the pulverizing is not so finely done as to cause the production of an excessive quantity of “slimes” in the succeeding operations, Krom’s rolls are particularly efficient. The Author has examined the tires of Krom’s rolls which have been in use for a considerable time, and has found their surfaces remarkably even and free from grooves. One of these machines had recently been employed with success to crush 8 tons of very hard emery-rock to 16-mesh, and the tires showed no trace of any hard usage. The Author has seen quartz crushed to pass through from 30- to 70-mesh by these rolls, the degree of fineness to which the rock can be pulverized depending on the number of times the product—after the finer particles have been separated by screening—is returned to the hopper. In gold-quartz dry-crushing operations

the very fine dust, which is inevitably produced in greater or smaller quantity—according to the character of the rock—and which is unlikely to carry with it any estimable quantity of gold, is separated from the valuable product by exhaustion with a fan driven at carefully regulated speed, and in this way there is little or no “sliming” and resulting loss of gold in the subsequent operations.

The average speed of the rolls is from 80 to 100 revolutions per minute. A pair of 26-inch rolls running at 100 revolutions per minute, gives a product of about 2 tons of gold-quartz of average hardness per hour, about 25 HP. being required for the working of the complete plant—Blake crusher, rolls, feeder, classifiers, elevator and fan.

As an index of the capacity of Krom's rolls, it may be stated that two sets of 26-inch rolls with faces 15 inches long give rather more effective crushing surface than fifty gravitation stamps, each 8 inches in diameter, falling at the rate of ninety drops per minute. In making this calculation the average diameter of the rolls is taken as only 24 inches, so as to allow for their gradual wearing, while their speed is taken at 100 revolutions per minute.

Krom's rolls are essentially dry-crushers; and before wet ores can be treated they require to be dried in a specially constructed furnace, or by some other method. The cost of this preliminary process must in certain cases be very heavy, especially where fuel is not easily obtainable; and, as the subsequent extraction of the gold from the pulverized ore is at present almost universally accomplished by a wet process or series of processes, the necessity for drying wet ores is one which will in many cases prevent the adoption of this method of pulverizing. On the other hand, if the ore be a more or less pure quartz, a small percentage of moisture will not prove a serious disadvantage. If, however, such slightly moist ore be at all argillaceous, the difficulty of treating it, without preliminary drying, will be a decided drawback; and, should the ore contain any significant quantity of clay, the product from the rolls will consist largely of thin flakes or cakes, which will not pass through an ordinary screen, and which will require puddling before the gold can be extracted by the amalgamation process. An aspirating contrivance is required for separating fine dust from the coarser product; while to effect very fine crushing there must be repeated screening, and a return of the coarser particles to the rolls. An accident to any part of the machine causes a stoppage of the whole; but this defect is of less importance if, as recom-

mended, a second pair of rolls is used in the operations, and, under proper management, accidents to the rolls are of rare occurrence.

These defects of Krom's rolls as gold-quartz pulverizers having been enumerated, there have to be set off against them the extremely simple construction of the rolls, combined with great strength and durability; the fewness of the wearing-parts, and consequent small cost of repairs; the great efficiency of the process, in that the ore escapes from the rolls immediately it is crushed, so that over-crushing is unlikely to occur; and the great capacity of the rolls, effective work being constantly done, and the amount of crushing surface brought into contact with the ore per minute being very large. The prime cost of the rolls is considerably less than that of stamps of the same capacity (see Appendix). For dry-crushing more or less pure and dry siliceous ores, especially where water is not abundant, the Author is of opinion that no more efficient pulverizer than Krom's rolls can be used. The special advantage of the rolls in the treatment of silver ores has already been alluded to. At the same time dry-crushing should not, in the Author's opinion, be adopted—whether by rolls or by stamps—unless the subsequent concentration of the pulverized ore and the separation of the gold is accomplished by dry methods. There are classes of gold quartz for the treatment of which rolls cannot be recommended as more advantageous than stamps or other mills, as, for example, quartzes in which the gold is extremely finely divided, wet ores—where the principal objection is the cost of drying—and argillaceous quartzes. It must not, however, be forgotten that the majority of gold quartzes are very free from argillaceous matter, and that, in general, they come to the mill in, at worst, a slightly moist condition.

3. STAMPS.

In gold-quartz reduction operations, the ore, after being more or less coarsely crushed in a stone-breaker, is generally subjected to pulverizing by "stamps" or "stampers," of which there are numerous varieties. "Gravitation stamps" are the almost universal form of these pulverizers, but there are a few special kinds of stamps which have given great satisfaction to their users, and a Paper of this kind would be incomplete without a brief reference to them.

(a) *Gravitation Stamps*.—A gravitation stamp-mill may be said, speaking generally, to consist of a row of heavy upright pestles—originally of wood shod with iron, but now wholly of iron, or of

iron and steel—which, ranged in line in batteries of five stamps each, are lifted by “cams” keyed on to a horizontal shaft rotating in bearings which are bolted to the “battery-posts” or standards. The pestles are lifted and allowed to drop in a certain order (1, 5, 2, 4, 3, or better 1, 4, 2, 5, 3), arranged with a view to securing the greatest crushing effect consistently with the preservation of the structure; and they fall upon ore fed into a mortar-box, the bottom of which is fitted with iron or steel dies to receive the blows of the stamps. The pulverized ore is ejected from the mortar through a screen or a stamped grating having meshes or perforations of regulated size determined by the nature of the particular ore under treatment.

Stamps appear to have had their origin in Cornwall, where they were used at least as far back as the seventeenth century. The old stamps consisted of beams of wood shod with iron, the weight of each complete stamp being about 150 lbs. at the outside. The number of stamps to a battery was from three to six, and they were raised by tappets projecting from the periphery of a revolving wheel. The wooden beam is now replaced in Cornwall by iron rods, the number of stamps in a line has been largely increased, while they are raised by tappets placed at intervals on a long horizontal revolving cylinder, somewhat resembling the pin-stuck barrel of a musical-box.

These rude contrivances were probably the earliest kinds of stamp used in California and Australia for the stamping of gold-quartz. During comparatively recent years the Cornish stamps, like the Cornish rolls, have been greatly improved upon, as the following description of a modern gravitation stamp-battery will show.

Fig. 8 represents in front elevation a wooden-framed battery of ten stamps, or, more correctly, two five-stamp batteries placed side by side, the amalgamating tables being removed to show the foundation timbers.¹ The several parts are as follows:—

- | | |
|---|-------------------------|
| A. Foundation timbers, or mortar block. | G. Screen. |
| B. Transverse sills. | H. Cam-shaft. |
| C. Battery-posts. | K. Stamp-stems. |
| D. Tie-timbers. | L. Pulley on cam-shaft. |
| E. Brace. | M. Driving pulley. |
| F. Mortars. | N. Belt-tightener. |

The framing is frequently made of iron, but, in practice, wood is found to be a far more satisfactory material.

¹ The figure is taken from the lists of Messrs. Fraser and Chalmers.

Fig. 9 represents a good form of single discharge mortar, the references being as follows:—*a*, stamp-stem; *b*, stamp-head; *c*, shoe; *d*, die; *e*, feed aperture of mortar; *f*, screen. And Figs. 10 to 14 represent ordinary forms of head, shoe, die, gib-tappet, and cam drawn to a larger scale.

A simple but most important feature of the gravitation stamp-mill is Wheeler's iron collar or "gib-tappet" (Fig. 13), secured to the upper part of each stamp-stem, by means of which the cam not only raises the stamp, but at the same time—by its friction against the underside of the tappet—causes the stem to partially rotate about its axis, this motion inducing a grinding as well as a crushing effect upon the material under treatment, and causing a more even wearing of both shoe and die than would otherwise ensue.

Messrs. Harvey and Co., of Hayle, Cornwall, are the makers of "high-speed revolving gravitation stamps," the peculiarity of which is that there are two cam-shafts, one above and one below the gib-tappets. By this means it is claimed that a speed of two hundred and fifty blows per minute can be satisfactorily attained; whereas in an ordinary stamp mill not more than ninety blows per minute can be obtained with a drop of 8 inches, as the head has not time to fall after leaving one "wiper" of the cam before the other strikes it up.

The weight of gravitation stamps—that is to say, of stem, gib-tappet, head, and shoe combined—varies with the hardness of the ore to be crushed, the figures ranging from about 450 to 950 lbs., or averaging about 750 lbs. For mere prospecting purposes smaller machines are constructed, the falling weight of whose stamps is ordinarily from 112 to as much as 300 lbs.

The amount of "drop" allowed varies from 6 to 9 inches or even more, the number of drops per minute being from seventy to one hundred, and in general about ninety. It is found in practice that within certain limits and under certain conditions increase of the number of drops per minute, *i.e.*, increase of speed, results in a proportionate increase of the yield of pulverized ore. These limits and conditions should be well considered by designers of pulverizing-machinery.

A most important consideration, that until recently was apt to be overlooked or underrated, is that the quantity of ore that can be treated by a battery of stamps depends very largely on the rate at which the pulp (in wet stamping) or the powder (in dry stamping) is ejected or exhausted from the mortar.

This discharge should be effected as soon as the ore is stamped

as fine as is required by the degree of fineness or coarseness of the gold disseminated through it, and the state of mechanical entanglement in which it may occur. Both over-stamping and under-stamping may result in considerable loss of gold, for reasons which will no doubt be obvious; so that the supply of water into the mortar, the size of the meshes of the discharge screen, and other details require careful consideration. The aim of the millman should be the ejection of the pulverized ore from the mortar the moment, but not a moment before, the free gold has been entirely separated, or, rather, broken out from its matrix. The amount of water fed into the mortar varies with the class of ore under treatment, the mean quantity being about 1,700 gallons per ton of ore stamped.

Mortars are made, when specially ordered, with discharge-screens on two, three, or all four sides, so as to permit of speedy ejection of the pulp. The best results are, theoretically at all events, obtained when screens of suitable mesh are provided on all sides of the box; while it has been estimated that a battery constructed with a screen on the front side alone is only one-half as efficient as a similar machine having a double-discharge mortar; that is to say, a mortar with a screen at front and back. The designing of quick discharging mortars requires great care, so that the rapid ejection of pulp may not be obtained at the cost of the durability of the mortar-box, excessive wear of the screens, or of satisfactory amalgamation in the mortar.

Automatic feeding of quartz into the mortar was designed not merely to economise labour, but also to prevent irregular and excessive filling of the mortar; and, while not in all cases satisfactory, mechanical feeders may be said to have largely effected their purpose. A detailed description of these contrivances hardly falls within the scope of this Paper; and it will be sufficient to say briefly that they consist in general of a pyramidal hopper, the bottom of which is hinged and connected with the feed-opening of the mortar-box by a slightly inclined spout or shoot, whose lower end is from time to time agitated—according to the quantity of ore in the mortar—by a lever or other arrangement acted upon by the gib-tappet on the stem of the middle stamp in each battery, a small quantity of ore sliding or being scraped down the shoot into the mortar at every such agitation. Self-feeders constructed with scrapers or “carriers” are to be preferred, especially with argillaceous ores, to those in which the ore is caused to slide into the mortar by the shaking of the shoot.

The duty or effective capacity of a battery of gravitation stamps

depends, then, on a large number of considerations, the more important of which may be summarized as follows :—

- I. The falling weight of the stamps.
- II. The number of drops per minute.
- III. The facilities for the discharge of the pulp or powder from the mortar. (Under this head come screen-area, water-supply, &c).
- IV. The hardness, or otherwise, of the ore.
- V. The size, or degree of fineness or coarseness, of the gold disseminated through the gangue.
- VI. The feeding arrangements, whether mechanical or manual.

The effective capacity of each stamp in a gravitation mill varies in accordance with these considerations from $1\frac{1}{4}$ to, in exceptional cases, as much as $4\frac{1}{2}$ tons of ore per day of twenty-four hours, 2 tons being approximately the average duty per stamp in an ordinary mill. About 2 HP. (actual) is required per stamp in such a mill. A mill of forty heads requires about 78 HP. (actual) for the driving of rock-breaker and stamps.

Before an opinion is expressed as to the correctness or otherwise of the principle of stamping as applied to gold quartz, it will be convenient to describe some of the more important of the numerous special forms of stamps.

(b) *Special Forms of Stamps*.—Under this head are included oscillating, pneumatic, steam, elephant, and other stamps.

Huntington's Oscillating-Stamp Mill.—This consists of a heavy vertical arm, forked at the lower end where two steel stamping shoes are affixed, the arm being made to oscillate in a vertical plane by a connecting-rod actuated by a crank keyed on to the end of a belt-driven shaft. The mortar in which the stampers work is fitted with dies in the usual manner. The oscillation of the arm causes first one shoe and then the other to strike the die or ore lying on it; and, the shoes sliding slightly along the dies, a grinding as well as stamping action is induced, which burnishes the gold and so facilitates its subsequent amalgamation with mercury. The construction of the mill is simple, and it is stated to give satisfactory results at some Californian gold mines in which it is used.

Pneumatic Stamps.—Of these the only important examples are Husband's Oscillating Cylinder Ore Stamper, and Sholl's Rotary Helico-Pneumatic Stamping Mill.

Husband's Stamper (Fig. 15) consists sometimes of one, but more generally of two stamps, the stems of which are attached to pistons of small diameter working in pneumatic cylinders, D,

which have a reciprocating up and down motion given to them by the revolution of a crank-shaft, C, with which they are connected by rods, E, coupled at their lower ends to trunnions, d', on the cylinders. The crank-shaft revolves on the bearings of plummer-blocks, B', formed on the bed or girder, B, which rests on the frame columns, A, being secured thereto by bolts. K is the coffer or mortar-box. The special object of the contrivance is to increase the rapidity of the blows beyond what is possible with the ordinary gravitation stamp, at the same time giving a longer drop than could be obtained with gravitation stamps required to run at high speed. The way in which this is effected is as follows:—Each cylinder is pierced with two rings of small holes, about $\frac{3}{8}$ inch diameter (see Fig. 16), one above, the other below, the central position of the piston; so that when the piston momentarily occupies the mid-position, air at atmospheric pressure fills both ends of the cylinder. The cylinder, being coupled to the crank-shaft by the connecting-rods, E, is raised by its rotation, the air in it below the piston is compressed, and the stamp thereby pushed up. Similarly, the downward motion of the cylinder causes a compression of the air above the piston, which urges the stamp down with greater velocity than it would have by virtue of its weight alone. It will be readily seen that the arrangement gives the stamp a fall several inches greater than that given by the crank. There is on some machines a contrivance for rotating the stamps, so as to induce even wearing of shoes and dies. The effective capacity of a single Husband stamp is stated to be about six times as great as that of an ordinary gravitation stamp of the same weight. The Author has seen stamps of this kind doing excellent work on tin ores; and there is good evidence that under proper management their working generally is attended with satisfactory results. A Husband's stamper of two heads, requiring 35 HP., has an output of 40 tons of hard ore per day. The air-cushions formed between the ends of the cylinders and the pistons, besides increasing the effective capacity of the stamps, obviate all excessive jar on the machine. Other advantages of the contrivance are its easy portability and comparatively small consumption of power. The Author is, however, of opinion that the Husband stamp, like the Sholl and steam-stamps (about to be described), is more suited for coarse and medium pulverizing than for very fine work, owing to the difficulty attending the use of thin screens in machines of such large capacity as these. Screens of fine mesh are necessarily very thin and of little durability.

Sholl's Rotary "Helico-Pneumatic" Stamping Mill differs from

the Husband stamp principally in that it is the piston that is directly attached to the crank-shaft (by means of a forked connecting-rod), the pneumatic cylinder being in one piece with a steel-shod ram or tup corresponding with the stamp stem and shoe of the Husband. The air-holes in the cylinder of the latter machine are represented in Sholl's mill by two opposite slots in the upper part of the air-cylinder, through which passes a steel-pin connecting the ends of the forked connecting-rod and carrying the pneumatic piston. The mills are made in two sizes, the smaller, driven by an engine of 10 HP. (indicated), delivering 140 blows per minute, and having a stated output of about 16 tons of hard gold quartz to 14-mesh per day; the larger requiring 20 HP. (indicated), running at 125 drops per minute, and stamping 24 tons per day to the same mesh. The Author has no data showing the results of finer stamping by this machine, and is more familiar with the Husband stamp; but he is inclined to think that Sholl's mill may, for coarse and medium pulverizing, be an efficient and satisfactory machine. The mill is simply constructed and very compact.

Steam-Stamps.—The ordinary form of steam-stamp consists of a direct-acting vertical engine, having a steam-cylinder and slide-valve at the top, the piston-rod being rigidly connected with the stamp. The stamp-head works in an iron mortar supported on timbers resting on cast-iron sills. The mortar has generally an all-round 'discharge; and there is less "sliming" than with gravitation stamps. Steam-stamps are largely used in America principally on account of their great capacity. The following Table shows the ordinary size and stated capacity of a variety of steam stamps made by a leading American firm:—

Diameter of Cylinder in Inches.	Length of Stroke in Inches.	Number of Blows per Minute.	Capacity in Tons per Twenty-four Hours.	
			Fine Crushing.	Coarse Crushing.
15	30	90	150	230

For the reason already given steam-stamps are more to be recommended as coarse pulverizers than for very fine work.

It will be readily seen that little or no saving of gold by amalgamation can be effected in the mortar of the ordinary steam-stamp.

A special form of steam stamp is *Fisher's Rotating-Bed Stamping*
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Mill in which the mortar is a rotating pan, of very strong construction, mounted on an inclined axis, and driven by a friction-roller working against its underside. The stamp is rigidly connected with the piston-rod of a direct-acting vertical engine, and there is a ratchet-wheel arrangement whereby it is made to partially rotate as it descends. The stamp-head is not permitted to strike the bed, a contrivance being provided for increasing or diminishing the distance between them, while the machine is in action, by raising or lowering the cylinder. The pulp is discharged through a screen surrounding the pan, the rotatory motion of which keeps the ore in constant agitation, and brings a change of material under the stamper at its every descent, thus to a certain extent preventing overstamping. The mill is not largely used, and its merits are doubtful.

The Elephant Stamp.—The construction of this machine, which is the invention of John Patterson, will be understood by reference to the accompanying perspective elevation (Fig. 17) of a two-stamp mill.¹

a, a are two bent or compound levers of hammered-iron or steel, one end of each of which is pivoted on a fulcrum-pin, *b*, stamp-shoes being affixed to the other ends in the usual manner. The levers are connected with the double-crank shaft, *c*, by strong semicircular springs, *d*, secured to short connecting rods, *e*. The stamp-heads work in a mortar, *f*, fitted with dies in the usual way, discharge screens being provided on three sides of the box, into which coarsely-crushed quartz is fed through an inclined shoot at the back. The peculiar principle of the machine consists in the action of the semicircular bow springs, *d* (compressed at their ends by the helical springs, *d*¹) introduced between the crank-shaft and the lever, which, receiving the force of the recoil from the blows of the stamps, store it up, and, giving it out at the next descent of the crank, effect a certain saving of power. Besides economizing power in this way, the springs act as cushions and take up a great part of the wear and tear of the machine. A mill consisting of two heads of elephant stamps is stated to be capable of stamping from 12 to 15 tons of hard gold-quartz per day of twenty-four hours fine enough to pass wet through screens of 30-mesh, or as much as 8 heads of ordinary gravitation stamps. They are considerably cheaper, lighter, simpler, and more easily transported, and erected than ordinary stamps, and are stated to require less driving power for the same effective capacity. The earlier forms

¹ The English makers are the Sandycroft Foundry Company.

of elephant stamp were by no means satisfactory in their working; but the contrivance has been much improved since its first appearance; and, in its present form, it may at least be useful as a prospecting plant, and in the development of new mines. Elephant stamps have been used in India with great success in preliminary operations, but have now been replaced by gravitation stamps, which are recognized even by the makers of the "elephant" as being better adapted for permanent working.

Miscellaneous Stamps.—Under this head may be classed

Hope's Compound Battery, which consists of two or more rows of stamps in one mortar box, the rows working at equal or unequal speeds according to desire. The mortar is provided with screens on all four sides, so that there is a large discharge area. The invention is a comparatively recent one, and its practical value is hardly yet determined. The Author is inclined to think that there must be considerable risk of the breaking of mortar-boxes, and great difficulty in cleaning up their interiors from time to time; while there must also be some complication and confusion in the lifting-arrangements.

Dunham's "Spring-Beam" Prospecting Stampers, in which the stamp-stem is attached to the longer arm of a laminated spring steel beam pivoted out of centre, and actuated by a crank driven at great speed. The mortar is fitted with discharge-screens on three sides. The object of the arrangement is to give a "rapid elastic blow" to the ore under treatment.

For prospecting purposes Dunham's invention may prove a useful machine because of its simple construction and light weight; and it does not claim to be more than a prospecting plant. The Author has, however, no trustworthy statistics showing its effective capacity on gold quartz.

The Merits and Defects of Gravitation Stamps.—Stamps are adaptable for both "wet" and "dry" pulverizing; so that their merits and defects may be considered under two distinct heads. In respect of both wet and dry pulverizing, however, the merits possessed by pulverizers of this class have principally to do with their construction, and they may be briefly summarized as follows:—

- (a) Simplicity of construction, notwithstanding the weight and number of parts;
- (b) The ease with which they are controlled, and kept in good working order;
- (c) No specially skilled mechanical labour is required for their repair;

- (d) In case of accident to any stamp in a battery, that stamp may be put out of action by a very simple mechanism, and the remaining stamps continue working as before until it is convenient to "clean up" the mill;
- (e) Whatever the theoretical defects of stamps, there is in practice, under proper management, no room for anxiety as to their accomplishing the amount of work for which they are designed.

On the other hand, there is a long list of defects, relating to both their construction and their principle, which must be carefully weighed.

As wet crushers, stamps are objectionable for the following reasons :—

- (a) Their great weight, and consequent heavy cost of transport, and necessity for very strong foundations.
- (b) Their heavy first cost.
- (c) The large number of wearing-parts, and consequent cost of renewals.
- (d) The cost of driving when water-power is not available.
- (e) The space required by the mill.
- (f) Effective work is done only at the instant at which the stamp descends on the ore.
- (g) The danger of over-stamping the ore, even when a large discharge area is provided, and the large production of "slimes;" while the pounding action may beat out the gold into thin leaf, which, floating on the surface of the stream of water passing over the copper plates, may be washed out into the tailings and lost. Also, the same pounding action may drive minute particles of quartz, &c., into the gold, or so coat its surface with impurities as to militate against the prompt amalgamating action of mercury upon it.
- (h) The risk of "flouring" and (with pyritic ores) "sickening" of mercury in the mortar-box, when amalgamation is effected therein.
- (i) The necessity for the use of oil as a lubricant of the cam-shaft bearings, &c., which is a risky matter, oil having a disastrous effect on the amalgamating process.
- (j) The great noise attending their use.

In addition to sharing these numerous defects, stamps as dry-crushers are objectionable, because in practice it is found that their capacity for such work is considerably less than their capacity as wet crushers; while the cost of the process is in certain cases very

large, because of the necessity for drying wet ores before they can be satisfactorily treated, which means an outlay of capital on mechanical dryers, fuel, &c., and additional labour; while aspirators and power for their driving have to be provided. And unless the powdered ore is subsequently concentrated and the gold extracted by a dry method, there does not appear to be any special advantage in drying wet gold ores before stamping. Indeed, dry-stamping of gold quartz is, in the Author's opinion, only economical and reasonable when water is not cheaply available at the mill.

There is, perhaps, no mining machine which has been subjected to such adverse criticism as the gravitation stamp, and which has yet held its own in practice so universally and for so many years without any immediate likelihood of falling into disuse.

As dry-pulverizers, the use of stamps cannot be recommended, except in the case of certain ores which require finer pulverizing than can be economically obtained by treatment with Krom or other improved rolls; and, speaking generally, the Author is decidedly of opinion that, in the cases in which dry-crushing is an advantageous process, Krom rolls cannot be surpassed by stamps or any other machine now in use.

The fact that stamps as wet-pulverizers have for so many years been, and are still, in such universal use should secure for them more respectful consideration than they are apt to receive at the hands of men who have obtained satisfactory results, for a more or less extended period, with some other form of pulverizing machine.

For the wet pulverizing of argillaceous, brittle, or soft gold-quartzes, the Author is inclined to think that the Huntington centrifugal roller mill, presently to be described, might with advantage be substituted for stamps. But, considering that a very large percentage of gold-quartzes are of extreme hardness and toughness, and can only be disintegrated by the application of immense pressure, which can be applied with great efficiency and economy by means of an instantaneous powerful impact, such as that given by a stamp, there will continue to be a large field of use for the gravitation stamp, despite its theoretical and practical defects. At the same time advocates of the use of stamps should be careful to guard against the too prevalent error of unconsciously blinding themselves to the merits of other pulverizing machines, some of which have a reliable and daily-lengthening record of satisfactory service.

4. ROLLER AND EDGE-RUNNER MILLS.

Under this classification come miscellaneous pulverizers which, to a certain extent at least, are modifications of the Chilian mill, so largely used in Mexico, Central and South America, in the "patio" process of silver-amalgamation. The number of such mills brought under public notice during recent years is very large, the majority, however, being of little or no practical value; and it will be sufficient to describe two varieties only of these machines, namely, the Bryan Roller Quartz-Mill, and the Huntington Centrifugal Roller Quartz-Mill.

(a) *The Bryan Roller Quartz-Mill* consists essentially of three iron or steel-tired rollers revolving on a horizontal iron or steel path at the bottom of a circular pan or mortar, the rollers being mounted on axes which rotate loosely round a solid centre post. The rollers are driven by a belt encircling a large drum or tank fitted loosely on to, and rotating round, the upper part of the centre post. This drum bears, as a constant weight, on the grinding faces of the rollers, and, by its rotation, causes them to revolve round the pan. Amalgamation takes place in the mortar, the pulp passing out, when sufficiently fine, through an all-round screen on to amalgamated copper-plates. It is claimed by the makers that as much as 70 per cent. of the free gold contained in ore treated in this machine is retained by amalgamation in the pan-mortar itself, and that "cleaning-up" is easily accomplished. The machine is made in two sizes, known as the 4-foot mill and the 5-foot mill. The following particulars of a 4-foot mill may be of interest:—

Diameter of Rollers in Inches.	Width of Rollers in Inches.	Weight of each Roller in Lbs.	Thickness of Tire in Inches.	Stated Capacity per Day, through Thirty Mesh, in Tons (2,000 Lbs.).
31	6	1,200	3	20 (about).

In certain cases, more especially where the ore has been a very free-milling quartz of medium hardness, the mill has given satisfactory results; but it is open to serious criticism on several grounds. It will be readily seen that, when the mill is running at full speed, the rollers must be thrown outwards by centrifugal force towards

the periphery of the pan with considerable straining of the centre post, and friction against the collars at the outer end of the axles on which they rotate. This means an appreciable waste of power, and wear and tear of the machine. Further, the rollers, running on the bed of the pan, are always violently agitating the bath of mercury placed therein; and with pyritic ores this must give rise to considerable "sickening" of the mercury, while in all cases there may be a certain loss of mercury by its being dashed out of the pan through the screen. The mill has a large number of wearing parts; and the Author is of opinion that there is room for further improvement in the details of its construction.

(b) *The Huntington Centrifugal Roller Quartz-Mill*.—This may fairly claim to be one of the most interesting and important wet-pulverizing machines brought into use during comparatively recent years.

Fig. 18 is a perspective sketch of the mill as made in America; while Fig. 19 is a sectional elevation, and Fig. 20 a plan of a four-roller mill of the English type.¹ Fig. 21 shows Mr. Paxman's improved form of roller-head and hanger, or yoke.

The mill is made in several sizes, the more usual being $3\frac{1}{2}$ feet, 5 feet and 6 feet in diameter. The $3\frac{1}{2}$ -foot mill has a capacity of 12 tons per day of twenty-four hours, and requires 4 HP. (nominal) for its driving; the 5-foot mill treats 20 tons in the same time, requiring only 6 HP.; while the 6-foot mill has a capacity of 30 tons per day, and requires 8 HP. The $3\frac{1}{2}$ -foot mill is not recommended except where transport is very difficult.

The following is a description of the 5-foot Huntington mill shown in Figs. 19 and 20:—A circular horizontal frame or disk-driver of cast-iron is keyed at its centre to a vertical spindle, G, which passes through the bottom of a sectional cast-iron shell in which the pulverizing is conducted. From the disk-driver, which is strengthened by having a wrought-iron ring shrunk on its periphery, are suspended four rollers, and as many scrapers; and the spindle, G, with these attachments, is made to rotate by bevel-wheel gearing under the wooden framework which supports the mill. The body of the scrapers consists of wood, and they are fitted at their upper ends into rectangular holes, A, B, C, D, in the disk-driver at different distances from the centre; their business being to throw the ore outwards to a circular steel ring-die against which it is pulverized by the rollers, and to prevent any accumulation at the centre of the pan. The method of suspension of the rollers is

¹ The English makers and patentees are Messrs. Davey, Paxman and Co., of Colchester.

extremely simple:—four pairs of pockets, P, are cast on the disk-driver near to its outer edge, and in each pair of these pockets bearings are formed to receive the ends of the “yokes” which carry the rollers. Fig. 21 is a sectional elevation of the latest improved form of roller and yoke (Paxman’s patent). It will be seen that the method of suspending the rollers permits of their swinging radially under the influence of a thrust at right angles to the line of suspension—that is to say, the centre-line of each pair of yoke-journals. When the mill is in action, centrifugal force urges the rollers outwards with great energy against the ring-die, which is wedged tightly to the inside of the shell. To strengthen the shell casting at this part, and prevent any fracture when the ring-die is wedged in, Mr. Paxman has a wrought-iron band shrunk on it externally. The Paxman patent roller-head arrangement is a great improvement upon the older construction shown in Fig. 19. With the old form it was found that the quartz worked under the rollers, causing the bolts fixing the bottom plate to work slack, and thus permitting grit to work into the interior of the heads, destroying the bearing surfaces; while further, the lubricating oil leaked into the pan. These defects are obviated in the new construction, which is as follows:—

The roller head is hollow and is made up of two separate castings, the “bearing sleeve” and the “roller.” The sleeve is fixed to the roller by T-headed bolts passing through slots in a flange on the latter, and holes in a flange on the sleeve. At the junction of sleeve and head a recess is provided, in order to receive a collar formed on the steel hanging-shaft, S, Fig. 21, to support the roller. On this collar one or more steel washers are fitted to take up the wear at this part. The hanging-shaft is firmly keyed to the yoke at the top so that it cannot rotate; it constitutes a central axis around which the combined roller and sleeve revolves. A chamber is formed in the roller-head to receive the end of the hanging shaft and to provide a receptacle for oil, which is introduced through a slot in the side of the said shaft. This slot is kept plugged at the top to prevent the entrance of grit. Each roller is fitted externally with a renewable steel ring, R, Fig. 21, which in the 5-foot mill is of 13 inches bore and $1\frac{1}{2}$ inch thick, this being fixed to the core of the roller by wooden wedges, about $\frac{1}{2}$ inch thick, tightly driven. A discharge-screen is fitted into the front half of the shell of the mill immediately above the level of the ring-die; and the pulp, on its ejection through this screen, passes at once over copper amalgamating tables, or direct to concentrators. The *modus operandi* of the mill is as follows:—From

40 to 60 lbs. of mercury are placed in the bottom of the pan, between which and the bottom of the rollers a clearance of an inch is allowed so that the rollers may pass freely over the mercury without coming in contact with it, stirring it up, and causing it to "flour." The central vertical spindle is set in motion by the bevel gearing, which is driven by belting; and this spindle in its rotation carries with it the disk-driver and its suspended rollers and scrapers. The average speed of the mill is about 85 revolutions per minute. Quartz—first broken by a Blake or other crusher—is automatically fed into the pan with water through the hopper, A, at the back of the mill. This quartz is thrown constantly against the steel ring-die by the scrapers, and the rollers—urged outwards by centrifugal force—come into contact with it, and granulate it. The free gold of the ore, as soon as it is liberated from its matrix, comes in contact with the mercury at the bottom of the pan; and a large percentage of the precious metal speedily forms an amalgam with it, the pulp being discharged, when sufficiently fine, through the screen or stamped grating. About 75 per cent. of the gold contained in the quartz is generally saved in the mill itself, the remainder being extracted from the pulp just as in the ordinary free-milling process. As the discharge of pulp is, though rapid, by no means violent, a screen of fine mesh—which means a thin screen—can be safely and satisfactorily used. The rollers granulate the ore, producing fine grit with comparatively little "slimes." The mill appears on that and other accounts to be particularly adapted for the treatment of ores containing brittle sulphurets, which, if pulverized by stamps, are liable to become "slimed."

For prospecting purposes and for opening up new mines there can be little doubt that, under proper management, the latest improved form of Huntington mill is one of the most economical and efficient machines; while, for certain classes of gold-ores, the Mill has been shown to be equal and even superior to stamps for permanent use. For argillaceous quartzes, which require a certain amount of "puddling" so as to liberate the gold, the mill is undoubtedly more efficient than stamps; while it is an excellent pulverizer of quartzes of a brittle or soft character, and an efficient grinder of coarse tailings. The mill has been at work on ores of medium hardness for several years, at a large number of American mines, with highly satisfactory results, in many instances entirely taking the place of stamps. There is, however, considerable wear and tear of grinding surfaces, that of the ring-die being the most significant; and for the pulverizing of the harder varieties of quartz, stamps would appear to be more economical and reliable

machines, both because of the wear and tear and of the speed at which the spindle is required to be driven in order to obtain sufficient pressure for the granulating of the rock. A gold-quartz dressing plant not unfrequently includes both Huntington mills and gravitation stamps among its fine pulverizing appliances. Other advantages possessed by this mill and not yet enumerated are:—its comparatively small cost and weight, its simplicity of construction and erection, the small power required for its working, namely about one-half that required by stamps of the same efficiency; the easy renewal of wearing-parts, continuous crushing, good amalgamation, large discharge-area, and the comparatively little noise attending its working.

One of the objections urged against the Huntington mill is that lumps of quartz may get into the centre of the pan out of the path of the scrapers. The Author's experience does not confirm this objection, and he is of opinion that, by reason of the arrangement of the scrapers at varying distances from the centre of the pan, such an accumulation of material, if possible at all, can only occur when the mill is overfed. The working of the mill undoubtedly requires intelligence and careful attention; and its failures, occasionally reported, may not unfrequently be attributed to unintelligent management, or to its application to ores of excessive hardness. The Author is, however, of opinion that there is room for improvement in the method of fitting the crushing rings on to the roller heads, so as to render impossible their loosening or falling off. Such an occurrence would obviously be attended with disastrous results. This matter of detail can be easily rectified. The following are among the precautions that should be taken to ensure satisfactory results:—

- (1) The ore should in all cases be fed automatically into the mill after being first broken into small pieces by a Blake or other crusher. When overfed there is danger that the ore may be dragged round under the rollers, raking up the mercury and causing some of it to be thrown out, and lessening the capacity of the mill.
- (2) The water-supply should be carefully regulated, the pulp being kept as thick as possible consistently with its prompt discharge through the screens when sufficiently fine. Should the pulp be too thick to run well over the copper plates outside the mill, water may there be added to it by means of a perforated pipe.
- (3) The speed of the 5-foot mill should not, as a rule, be less than 70 revolutions per minute. With many ores a speed of more than 85 revolutions is necessary in order to effect their disintegration.

(4) The Mill should be stopped about every six hours, to see that every part is in good order. These stoppages will not mean any serious loss of time.

5. BALL PULVERIZERS.

These are machines in which ore, coarsely crushed by a Blake or other machine, is finely pulverized by the action of a ball, or of balls, of chilled iron, steel, or other durable metal revolving on a circular track. There are numerous varieties of ball pulverizers, of which may be mentioned—

(a) *The "Cyclops" Mill*, in which a single free ball of special hard metal, sometimes as much as 12 inches in diameter, is carried round in a vertical plane by frictional contact with a pair of flexible disks fitted on a horizontal revolving shaft. The grinding is done between the ball and a grooved circular steel path formed on the inner side of the shell enclosing the ball and disks. The mill is adapted for both wet- and dry-pulverizing, and, for the wet process, discharge-screens are fitted on two sides of the pulverizing-chamber. The largest machine is stated to be capable of treating 2 tons of gold quartz per hour, the required driving power being 16 HP. (nominal). The principal objection to this mill is that the motion of the ball is, during one half of its revolution, against gravity, which entails a certain loss of power, uneven expenditure of force, and irregular wear of the grinding-surfaces, added to which the construction of the mill is somewhat complicated, and its weight very considerable. The machine as now made is, so far as its constructional details are concerned, an improvement upon the original "Globe" mill, and it undoubtedly has a large effective capacity. The Author is, however, of opinion that it has not yet made a sufficiently lengthy and good record to establish its claims to supersede stamps and other pulverizers of proved reliability, while the objections above mentioned will render its extensive adoption as a reducer of gold-quartz improbable.

(b) *The Lamberton Grinding-Mill*, in which the pulverizing is done by a number of rolling balls driven round a horizontal grinding-track of cup-shaped section, by a heavy rotating disk, which bears on the top of them. The horizontal grinding-path is decidedly preferable to the vertical track of the machine just described, but the amount of wear and tear of surfaces in the crushing chamber must be very great.

(c) *The Ball Mill*, which consists of a strong metal drum, supported on a central axis, and having nine perforated inclined metal plates, or shelves, arranged on its inner circular surface, in such a way as to form steps, or inclined planes, on which roll a large

number of small hard metal balls. When the drum revolves, the balls have a rotary motion imparted to them, but drop from step to step as the revolution of the drum proceeds. The material under treatment is thus subjected to a stamping as well as a grinding action. The pulp, wet or dry, is discharged through a screen surrounding the drum. A "Ball mill" of 6 feet diameter weighs, without balls, 130 cwt., requires 10 HP. for its driving, and has a stated capacity of 1,700 lbs. of gold or silver quartz per hour to 60 mesh. There must be considerable friction between the balls themselves, and great wear and tear of the grinding-surfaces generally, necessitating frequent renewal of parts. A large area of grinding-surface, such as that on which these balls operate, is as a general rule undesirable, because of the great wear and tear involved.

(d) *Morel and Hall's Ball Mill*, in which six steel or hard metal chilled balls, about 8 inches in diameter, are propelled round a horizontal circular crushing-path by as many arms keyed on to a vertical shaft rotated by bevel gearing. Where it is desired to save the free gold in the mill, a separate compartment is provided below the crushing-chamber, into which the pulp is allowed to pass through a screen.

(e) *Jordan's Fine Reducer or Pulverizer*, which consists of a revolving cone-shaped pan, mounted on an inclined axis, and carrying three heavy balls of white iron, which work on a white iron bed around the greatest inner circumference of the pan. The interior structure of the pan and the inclination of the central shaft are so arranged that, when the ore is sufficiently comminuted under the rapidly revolving balls, it is washed over wire screens, and passes out into a launder, which conveys it to a special form of "amalgamator or extractor," constituting part of Jordan's "centrifugal gold-process." The machine has given good results in certain trial experiments, while in one instance the plant has been running regularly from fifteen to eighteen months on highly refractory gold-ores, with very satisfactory results. The pulverizer is very favourably regarded by many engineers; but before its practical value can be absolutely established, the results of its work on large quantities, at a number of mines, must be obtained and considered relatively with those of other machines now in larger use.

Speaking generally of pulverizers on the Ball principle, the Author is of opinion that, while the better varieties may have a certain utility as grinders of ore already more or less finely comminuted, their claim to rank as equal with, or even superior to, stamps and rolls as pulverizers of roughly-crushed ore as it comes from the Blake or other first breaker, is not yet confirmed by the

results of their working on large quantities; while many of the ball pulverizers brought into public notice during the past ten years have proved, if not entire failures, most uneconomical machines, by reason of the great wear and tear of the grinding surfaces and the driving power required.

6. PNEUMATIC PULVERIZERS.

The following are the principal machines coming under this classification:—

(a) *The "Pneumatic Pulverizer"* of the British and Foreign Pneumatic Pulverizer Company. The principle "consists in the employment of two powerful opposing currents of superheated steam or air, so arranged and adjusted that they continuously charge themselves with material, already coarsely crushed or granulated; and by the great force and velocity of the currents, these particles or fragments of mineral are dashed against each other with such concussive force as to cause them to be pulverized to an impalpable dust." It is stated, by way of proof of this assertion, that "one of the most difficult ores, chrome iron, has been pulverized continuously for many months" by one of these machines. The makers claim that the high temperature of the currents employed, through which every minute particle of ore must pass, causes them to become very hot and dry, producing a beneficial effect upon sulphurets and ores containing so-called "rusty gold." The pulverizer is of somewhat complicated construction, and, so far as the Author is aware, is not much used in gold-quartz reduction operations.

(b) *The Cyclone Pulverizer*, in which two blades or fans revolve in opposite directions at enormously high speed in a small chamber, producing strong opposing currents of air. These counter currents cause a speedy disintegration of pieces of rock, fed into the chamber by hurling them against each other. There is a special pneumatic contrivance for sizing the product. The machine is made in three sizes, of which "No. 2" is in greatest demand. The following particulars of this pulverizer may be of interest:—

Machine.	Nominal HP. required.	Output per Hour. (Mesh not stated.)
No. I.	6 to 8	4 to 12 cwts.
„ II.	12 „ 18	15 „ 50 „
„ III.	25 „ 35	40 „ 100 „

In machine No. 2 the fan-spindles are required to revolve at the high speed of 2,000 revolutions per minute in opposite directions, and it will be noticed that a considerable expenditure of power is required for the output obtained.

(c) *The Leviathan Pulverizer*.—In this mill the coarser pulverizing is largely effected by the material colliding against itself between two circular steel grinding plates with serrated faces, mounted on horizontal spindles, which are made to revolve in opposite directions. The finer pulverizing is done by the serrated faces of the plates over which the ore is urged outwards by centrifugal force. The ore is first broken small in a close-set Blake, and introduced into the machine through a hopper at the top of the wrought-iron cover which encloses the plates. The mill can be used for both wet and dry pulverizing.

(d) *The Sturtevant Mill*.—In this the rock is reduced to powder by the action of the fragments upon themselves in the following manner:—The mill is composed of two cylindrical metal cups or heads, arranged on the opposite ends of a cylindrical case, into which they slightly project, facing each other. The heads are made to revolve in opposite directions, and the material to be pulverized is conveyed into the case through a hopper at its top. The heads, being in motion in opposite directions, hurl their respective contents into collision with such enormous force that the rock is at once crushed to atoms, the powder passing out of the mill through a screen contained in the case, and thence into a bin below. The following Table gives the dimensions, capacity, speed, and other particulars of various sizes of this mill:—

Size of Mill.	Largest size of Material to feed Mill.	Capacity in Lbs. per Hour to pass Ten Mesh.	Capacity in Lbs. per Hour to pass Forty Mesh.	Outside Dimensions of Mill—Length and Width.	Weight of Mills in Lbs.	HP. required.	Number of Revolutions per Minute.
6 ins.	2 cub. ins.	500 to 1,000	..	feet. 4 7 × 26	1,100	10	2,600
8	2½	1,000 „ 3,000	500 to 1,100	6 9 × 28	2,335	20	2,000
12	3½	10,000 „ 20,000	2,000 „ 8,000	9 7 × 35	4,625	45	1,300
20	4½	15,000 „ 30,000	4,000 „ 10,000	14 8 × 56	17,775	75	850

The high speed at which these and other pneumatic machines require to be driven is a decided disadvantage, the cost of driving being heavy, and the bearings of the spindles requiring great and constant attention. It will also be noticed that in the Sturtevant

mill—as in the Cyclone Pulverizer—a very large amount of driving power is required per ton of fine produce. The Sturtevant appears to be used by a large number of American mining and metallurgical companies; but the Author is not in possession of trustworthy data, showing the results and cost of its working on gold-quartz, where large quantities have to be constantly treated.

7. MISCELLANEOUS GRINDERS OR PULVERIZERS, NOT INCLUDING PANS.

(a) *The Niagara Mill*, a combined pulverizing and separating mill for dry-crushing. This machine consists of a metal drum mounted to rotate on a hollow horizontal axis, or trunnion, by double-helical tooth gearing, and containing a heavy edge-runner which rolls in contact with the periphery of the drum. The material to be ground is, after coarse-crushing in a Blake or other machine, fed into the drum through an opening in front of the same width as the edge-runner. On each side of the interior of the drum a circle of wedge-shaped cups is fixed for the purpose of scooping up the pulverized ore after it has passed under the runner; and these cups carry it up to the highest point attainable, where, reversing their position, they allow the ore to fall out. During its fall, the finer parts of the ore are exhausted from the drum through the hollow trunnion by means of a fan, while the coarser parts fall to the bottom of the drum, and again pass under the roll. This process is continued until the whole is reduced to the required fineness, which is regulated by the speed at which the fan is driven. The drum makes 25 revolutions per minute. For the grinding of certain classes of rock, these mills may temporarily be useful machines; and the Author has seen them treat small quantities very successfully. The makers claim that a mill requiring 6 HP. only is capable of pulverizing 30 cwts. per hour to pass through 80 mesh. But, where dry-crushing is advantageous, Krom's rolls are unquestionably to be preferred as a permanent plant, not merely because of their larger effective capacity, but also on account of their greater durability, and for general structural reasons.

(b) *The Howland Pulverizer*.—In this machine, which the Author has had no opportunity of seeing at work, the pulverizing is done by twelve disks or rolls, each 10 inches in diameter by $4\frac{1}{2}$ inches in thickness, which lie on one of their flat surfaces on an iron carrier-plate, secured to a central axis and made to revolve inside a circular pan by bevel gearing under the supporting framework.

A circular ring-die is fitted into the lower part of the pan, and, the carrier-plate revolving at high speed, the rolls are thrown outwards by centrifugal force and rotate, by frictional action, against this ring-die, on which they pulverize any ore coming between them. The pulverizing action resembles that which takes place in the Huntington mill, which, however, is a much more compact, reliable, and economical machine.

8. GRINDING- AND AMALGAMATING-PANS.

A grinding- and amalgamating-pan may be said, briefly and generally, to consist of a circular tub or pan of cast-iron, or some other durable material, provided on the inside with a renewable false bottom of cast-iron—constituting the lower grinding-surface—and a “muller,” or upper grinding-surface, mounted on a vertical spindle, and made to rotate by bevel wheel or other gearing below the pan. The business of the muller is to grind to minute particles ore already more or less finely reduced by stamps, rolls, or other machines, and subjected to subsequent concentration; and, secondly, to effect an amalgamation of the gold contained in the pulp with quicksilver introduced into the bottom of the pan.

The origin of these fine-grinding appliances, of which there is an almost endless variety, may, in many instances, be traced either to the horizontal millstones still used in certain countries for grinding corn, or to the rude Mexican arrastra.

Small “improved arrastras” are now made by several firms. One variety of these consists of a sectional wrought-iron pan, fitted with a granite grinding-bottom and granite mullers, the latter attached to arms projecting from a vertical spindle rotated by manual or mechanical power. For prospecting purposes some of these improved arrastras have considerable merit. Besides machines to which the name “arrastra” is applied, there are other forms of pan—as, for example, the Berdan—in which the same principle is distinctly traceable. As now constructed, the Berdan consists of a circular cast-iron pan, about 4 feet in diameter, mounted on the lower end of a spindle, which is made to rotate in an inclined position by bevel gearing at the top. The grinding-track of the pan is semi-circular in section, while the upper grinding surface consists either of two cast-iron hemispherical mullers attached by chains to the framing, or of a cast-iron ball, of nearly the same diameter as the lower grinding surface, which revolves freely as the pan rotates.

Fig. 22 shows in section a flat-bottomed pan of a form in very general use. The distance between the grinding-surfaces is regulated by adjusting the centre-screw by the hand-wheel.

It is impossible in this Paper to describe any of these pans in detail. They differ in having flat, conical, or conoidal mullers and bottoms. In some pans—as, for example, in the Wheeler pan—there is at the bottom a chamber into which steam is introduced for the purpose of heating the pulp. In others, as, for example, in Hepburn and Peterson's, steam is introduced directly into the pulp itself; while there are numerous special forms of muller grinding-surfaces (independent of the sectional shape of the muller) and various methods of raising and lowering them.

A most important consideration in grinding-pan operations is the consistency of the pulp. It frequently happens, especially in the case of those pans into which steam is directly introduced, that the pulp becomes too thin to permit of a proper dissemination of mercury globules throughout its mass. The mill-man should see to it that, while the pulp is kept sufficiently fluid to allow of its constant circulation in the pan, it should yet be so consistent as to be capable of holding in suspension the finely-divided globules of mercury whose repeated collision with the particles of gold contained in the pulp is so essential to the process of pan-amalgamation.

GENERAL CONCLUSIONS.

Before any permanent pulverizing-plant is selected for the treatment of gold-quartz at a mine, the nature of the ore—that is to say, its physical structure and mineral and chemical composition—should be determined as nearly as possible by examination in bulk, while the working facilities at the proposed mill-site should be as carefully considered.

For the preliminary coarse-crushing of the ore, the Blake, the Gates, or the Comet breaker will in nearly all cases be found efficient machines; the fine-crushing Dodge being more particularly suited for mills of moderate capacity.

In choosing a plant for the finer pulverizing of the ore, the relative merits of stamps, rolls, roller-mills, and other appliances, require to be well weighed. The Author has already expressed his opinion as to the classes of work for which these different machines are more particularly suitable; and it is therefore only necessary to recapitulate in a summarised form.

For wet-pulverizing, the appliance which has most success-
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fully competed with stamps is, in the Author's opinion, the Huntington centrifugal-roller quartz mill, which has been shown to do excellent work on brittle and soft gold-quartzes, while it is peculiarly adapted for the treatment of pyritic ores carrying a tolerably large percentage of free gold, and for argillaceous quartzes which require a good deal of "puddling" before the gold can be liberated from the valueless gangue. For quartzes of more than medium hardness, however, the Huntington mill is not so efficient or economical as gravitation stamps, owing to the great pressure that has to be applied in order to effect the disintegration of such ores, and the great wear and tear of grinding surfaces which necessarily ensues when they are treated in such a mill. For the wet pulverizing of hard gold-quartzes, well constructed gravitation stamps working in rapid-discharge mortars give results which, if not in all respects as satisfactory as could be desired, are undoubtedly better than any yet obtained, on a large scale, from other wet-pulverizing machines.

For dry-pulverizing, except where extremely fine comminution is required, stamps do not in practice give nearly such satisfactory results as those obtained with them by the wet method, and the Author is of opinion that, where dry-crushing is a necessity, or an indisputable advantage, and where the subsequent processes of gold-extraction are conducted by dry methods, Krom's rolls are to be preferred as pulverizers. The limitations affecting the use of rolls as gold-quartz reducers, and the circumstances under which dry crushing can be advantageously adopted, have already been sufficiently discussed.

The essential requirements of machines intended for the crushing and pulverizing of gold-quartz may be summarised as follows:—

Essentials Common to both Coarse-Crushing and Fine-Pulverizing Machines.—Prime cost, weight, number of wearing parts, power for and speed of driving, should be kept at the minimum consistent with strength and efficiency. Simplicity of construction, erection, and working, and easy renewal of parts as they become worn, are important considerations, while the wearing parts should possess great durability.

Essentials Peculiar to Fine Pulverizers.—The pulverizing of the ore should be accomplished with the production of the least possible amount of excessively fine "dust" or of "slimes," to the formation of which large losses of gold are frequently attributable. To this end, the mortar should be so constructed that the pulp or powder may be discharged therefrom as soon as possible after the ore has been sufficiently finely comminuted to liberate the gold from its

matrix. To borrow an illustration which has been used elsewhere, the ideal form of pulverizer is one which breaks the quartz and liberates the gold from its matrix just as the kernel of a nut is liberated by the breaking of its shell with as little injury as possible to the kernel. The Author has endeavoured to show in what respects gravitation stamps fail to accomplish this end, and that the granulating action of the Huntington mill is a most important point in its favour, as against the pounding action of stamps.

Within the limitations detailed in this Paper, the Author is of opinion that there is a large field of use for gravitation stamps, for the Huntington mill, for Krom rolls, and for certain of the other pulverizers which have been named, at the same time that there may still be room in which inventive genius may work; while the prejudice which, rightly or wrongly, exists against some forms of pulverizers may be largely removed as their record of work lengthens.

The communication is accompanied by a series of drawings from which Plate 3 has been compiled.

APPENDICES.

APPENDIX I.

TABLE SHOWING COST, CAPACITY, &C., OF FINE PULVERIZERS.

Krom Rolls (single set).

Dimension of rolls	{ Diameter 26 inches.
Average capacity per day (medium fineness)	{ Length 15 "
Actual HP. required (for complete process, including crusher)	{ Tons, 48.
Revolutions per minute	{ 25 (about).
Total weight	{ 80 to 100.
Price	{ Tons, 7½.
	{ £440.

Stamps.

	750 lbs. Gravitation Stamps (Wooden Frames).		Husband's Stamps.	Elephant Stamps.
Number of stamps	10 Tons.	20 Tons.	2 Tons.	2 Tons.
Average capacity (medium fineness)	20	40	40 to 50	12 to 15 Nominal.
HP. required (for stamping only)	20	35	35	5
Drops per minute (average)	90	90	140	200
Total weight Tons	16 to 17	31 to 33	13	2½
Price	{ £460 to £475 }		{ £900 to £920 }	{ £550 £200 }

Huntington Mill.

Diameter Feet	3½	5	6
Average capacity per day (medium fineness) Tons	12	20	30
Nominal HP. required	4	6	8
Revolutions per minute	90	70	55
Approximate weight Tons	8½	5	9
Price	£175 (about)	£312 10s.	£469

The above prices do not include ore-breakers, engines, or boilers. In the case of the Krom Roll plant, power is included for a fine-crushing Blake ore-breaker, so essential to the success and durability of this form of pulverizer.

Prime cost is in reality a secondary consideration in selecting reduction machinery. Weight determines the cost of freight and transport; and, in certain countries, the latter item may amount to as much as from £10 to £20 per ton. Where water is not available for driving purposes, the amount of power required is an economic consideration of enormous importance. Cost of re-

newals of worn parts constitutes another important item, more especially in the case of gravitation stamps, where the number of wearing parts is very large. The average consumption of iron for shoes and dies in California is about $1\frac{1}{2}$ lb. per ton of quartz in dry-crushing, and $1\frac{1}{2}$ lb. per ton of quartz in wet-crushing; while the whole wear and tear of the plant, including cams, tappets, &c., may be taken at about 2 lbs., or 5d. per ton of quartz crushed. Steel shoes and iron dies have a longer life than steel shoes and steel dies. Chrome steel has during recent years come into considerable use in America for shoes. The average cost of crushing with the Huntington Mill—stated by some questionable authorities not to exceed $1\frac{1}{2}$ d. per ton, including power—is, at present, a figure difficult, if not impossible, to approximate; but the wear and tear is very considerable with ores of more than medium hardness, and to crush very hard quartz with that machine would be an exceedingly costly process. Other economic considerations that should influence the choice of a pulverizing plant are the cost of preparing a mill-site—including foundations—and of erecting suitable buildings to cover the plant. The weight and dimensions of the machines govern these details. The simplicity or otherwise of the machines regulates the cost of management.

APPENDIX II.

EFFECTIVE HP. REQUIRED PER TON OF QUARTZ.

Variety and Brief Particulars of Pulverizer.			Effective HP. required per Ton of Produce to 30-mesh, including Allowance for Stone-breaker and Friction.
Gravitation stamps .	Weight of each stamp	750 lbs.	0.80 to 1.00
	Number of drops per minute	90	
	Average duty per stamp per twenty-four hours, to 30-mesh	2 to $2\frac{1}{2}$ tons	
	Effective HP. required per stamp, including allowance for stone-breaker and friction	2	
	Variety of mortar	{ Single-discharge }	
Huntington mill. (Size, 5 feet diameter). .	Average duty of mill per twenty-four hours to 30-mesh	20 tons	0.67 to 0.70
	Effective HP. required by mill, including allowance for stone-breaker and friction	13.5 to 14.0	
Krom rolls	Dimensions of rolls	{ Diameter, 26 inches Width, 15 inches .	0.54
	Average duty per twenty-four hours, to 30-mesh	48 tons	
	Effective HP. required, including allowance for stone-breaker and friction	26	

In this Table the mortar in which the stamps work is assumed to be of the ordinary, or single-discharge, type. Mortars constructed with front-and-back, all-round, or front-and-end screens give a largely-increased output, the effective HP. required per ton of quartz being correspondingly decreased. The use of rapid-discharge mortars is, however, attended with inconvenience on many accounts; and, as a rule, they cannot be recommended for non-pyritous free-milling quartzes, because the pulp is ejected from such mortars before a sufficient time has passed for proper amalgamation therein. In an ordinary single-discharge mortar as much as from 75 to 80 per cent. of the gold may be, and is frequently, saved by "battery amalgamation," so that the objection just stated is of great importance. On the other hand, rapid-discharge is very desirable when the ore under treatment contains troublesome sulphurets, the fine pulverizing of which would result in the production of "alimes," from which the gold is only separable with extreme difficulty. In mortars with end-discharge, the two outside stamps (1 and 5) are considerably more effective than the corresponding stamps in dead-end mortars. Under the Hornsby-Ogle patent the mortar has an all-round discharge, the ends of the box being made circular instead of square, and fitted with circular screens.

The Table deals only with medium-grade pulverizing, and should therefore be considered side by side with the Author's earlier remarks on the precise varieties of quartz and the degrees of comminution for which the more important pulverizers are especially suited.

Discussion.

Mr. A. H. CURTIS said he wished before the discussion commenced Mr. Curtis. to make a few supplementary observations. There was a contrivance coming under the designation "Ball Pulverizers," to which he had made no specific reference in his Paper, for the reason that he had only quite recently become acquainted with its construction. He referred to the Crawford mill, a model of which had been exhibited in the library. In that machine the grinding was effected by, he thought, eight hard metal balls on a circular horizontal grinding-bed. The contrivance was one of the most ambitious and ingenious of its class, more especially in regard to its method of separating the gold from the valueless pulp by the introduction into the machine of water under pressure. The weight of a small Crawford mill, having a capacity of $2\frac{1}{2}$ tons per twenty-four hours, was about 45 cwt. The power required for driving appeared to be reasonably small, and the consumption of water low. The wear and tear of grinding surfaces was, however, a serious item; and the matter was, he understood, engaging the close attention of the makers. He should be interested in the further development of the mill, and, speaking generally, he was distinctly in favour of granulation as against pounding. At the same time he regarded the wear and tear of grinding surfaces in ball pulverizers generally as a grave defect, the efficiency of the balls being impaired when only a very small reduction of their diameter had taken place, while their spherical shape was not always preserved. Some further particulars relative to the Huntington mill might be useful. In a 5-foot mill the ring-die weighed 611 lbs., and each of the four roller-shells weighed 140 lbs. The latest information in his possession was that the roller-shells crushed from 900 to 1,100 tons of quartz, and the ring-die about twice that quantity before they required to be replaced. Taking the total weight of the roller-shells and the ring-die as being worn out after crushing the quantities stated, it was easily deducible that the consumption of steel per ton of quartz was about 0.866 of a pound, or $2\frac{1}{4}d$. The wear and tear of other working parts was very slight. As little as from 17 to 25 lbs. of mercury was stated, on good authority, to be a sufficient charge for the pan of that mill. They were, however, in his opinion more concerned that evening with principles of working and the quality of results

Mr. Curtis. obtained than with minute details of construction, and it was on those important matters that he ventured to expect criticism and information. He regretted very much that he had not been able to treat of amalgamation, concentration, and other processes which were of very great interest and importance to gold miners. The subject of reduction—crushing and pulverizing—was of itself sufficient for a single Paper, and he must leave to other and abler hands, or at any rate to another Session, the task of bringing before the Institution the important subjects of which he was then unable to treat.

Mr. Western. Mr. CHARLES R. WESTERN said that the Author had brought before the meeting all the machines in general use for the reduction of gold quartz, and he thought had fairly criticised them. Among the newer systems of crushing was that of rollers, in which he was particularly interested. The Author had not, he thought, very accurately presented to the meeting the fact that crushing by rollers was really a system, seeing that he had only described it as a machine. He (Mr. Western) wished to describe shortly what the system of crushing really was, because its success was due to the system as much as to the machine itself. The process was substantially similar to that of the flour-roller mills in use for a great many years, and probably known to all the members. The principle of the system was gradual reduction and constant separation. In other words, instead of doing all the reduction, from the size of a piece as big as one's hand to the size that might be eventually required, in one machine, as in a stamp battery, it was done gradually in the system in which the Krom rolls formed a part. The system consisted in putting the ore first through a stone-breaker, which reduced it to the size of a hen's egg. In that first process of reduction a certain amount of small would be made which was then separated, the separated parts going direct to the rolls, which formed the main feature of the system. It was then passed through a second stone-breaker specially made so as to crush fine, which reduced the ore to the size of a broad bean, the most suitable size to go through the rolls. In that second reduction, again, a large amount of fine would be made, and this was at once separated by a sieve, and went away to the end. The ore from the second breaker was then fed to the rolls in an even stream, and probably 80 per cent. of the ore was reduced at one passing through to the required size; the remaining 20 per cent. being then returned either to those rolls, or to a second set of rolls. It would thus be seen that the principle of the system was that of gradual reduction. In the particular case

which he had described, there were certainly three reductions, Mr. Western. and even a fourth for what was returned to the rolls from the finishing screen. The stamp battery was of course the best machine in use hitherto, and the most largely used, and would always continue to be used. In it, the ore had to be reduced by a single machine, which could not possibly be properly designed for such a great variation of work, such as reducing ore of the size of one's fist until it was small enough to pass through a sieve half a millimetre wide, whereas in the Krom roll system this work was done gradually. The importance of the system was seen in the result—the cost of crushing 1 ton of ore to a certain required size. He had found by experience that by the system of gradual reduction, although there were more machines used, there were two advantages. The first, which was the most important, was that the resulting crushed ore was much more nearly of the required size for after treatment than when it was pulverized by any system of stamps or edge-runners, or by any frictional system. Secondly, the power required to do the work per ton of ore was less. With regard to the exact figures, it was difficult to make accurate comparisons, because one usually had not the same material to deal with in the two processes. He might mention, however, that the other day he had two ores, one of which had been pulverized by stamps at one of the Cornish mines. The standard size of pulverizing there was equivalent to 25 by 25 mesh. It was found that 97½ per cent. would have passed through the 40 mesh and 74 per cent. would pass through an 80 sieve; but it was not required to do more than pass through the 25 mesh. The method of working was wrong. Presuming that 25 was right, it was unnecessary to pass 97 per cent. through a 40. In order to compare this result with that of the Krom rolls, he selected a tin ore from the Straits, which seemed to be of a very similar nature, and about 15 tons were crushed. He found that after all had passed through a 25 sieve, 45 per cent. would not go through a 40 sieve, showing that 45 per cent. only varied in size between a 25 by 25 and a 40 by 40, which was very good crushing indeed. To show the small quantity of fine that was obtained, it might be noted that only 24 per cent. would pass through an 80 sieve, as against 74 per cent. of the Cornish crushed ore. That was only one case, and it could not be taken as a strict comparison, because the ores would behave differently according to their nature, but it might be taken as typical. Whatever ores were taken, there was the same kind of difference, but not, perhaps, the same extreme proportions as he had men-

Mr. Western. tioned. The next point of importance in Krom rolls was the question of power, which he thought had never been sufficiently considered by owners of mines. Power meant coal and money. Mines were generally in out-of-the-way parts of the world, fuel was dear, and it was a large item, and if it could be reduced by 30 or 40 per cent. the matter was well worth while looking into. It would be interesting to engineers and, at all events, to manufacturers, if the Author would give a comparative Table, stating the actual power per ton of ore crushed by the various systems which he had described. He had given in his Paper certain powers, but in a confused way. Nominal powers were given, but he (Mr. Western) maintained that nominal HP. was a useless term to an engineer, conveying no accurate idea whatever. The only way was to give effective or indicated HP. Indicated power was what they wanted; it meant the quantity of coal consumed. Having special opportunities, he knew exactly to 1 HP. what was required for crushing on the Krom's roll and other systems. For the purpose of comparison, it might be stated that to crush 2 tons of ore with a single roll-plant, like that shown in Figs. 5, 6, 7, with a capacity of 2 tons of ore per hour, fine enough to pass a sieve 30 by 30, containing nine hundred holes per square inch, about the average size required in practice, the power for a complete plant, with two stone-breakers and the necessary screens, engines, and shafting, was 32 indicated HP., of which the roll itself only used 11 I. HP. when it was all in full work. A twenty-head stamp battery would do about the same work—it did not matter what the ore was—with 35 I. HP. That was about what it would use as a single machine. But it was an incorrect comparison to make; the real comparison was what would the plant do. A twenty-head stamp battery required a stone-breaker, or two stone-breakers and feeders, and an engine to drive. For these, together with the friction of the shaft, there would be required over 50 HP. as against 32 HP. for more accurate work by the Krom roller system. He thought he had explained generally the points of the system, but he should like to correct two points in the Paper that were erroneous according to his view. The Author had referred to the Krom roll system as a dry crushing system. It was so; they only made and sold it as a dry-system. They had only used it as such, but he supposed there would be no difficulty in making it crush wet. The Author had stated that it was only suitable for crushing ores, after they had been dried, in most cases, artificially. That question of drying was not distinctly understood. Nothing was absolutely dry. It

was entirely a relative question. As long as ore did not contain more than about 5 per cent. of moisture, there would be no difficulty in crushing it by the system described. There were very few mines that produced ores that by the time they got to the mill had anything like 5 per cent. of moisture. They appeared to be wet all over, but the percentage of moisture was relatively nothing. As an experiment he immersed in water a piece of *banket* from the Transvaal. He left it for ten minutes. It was a small piece—1,000 grains. After it had remained in water ten minutes the total amount of water it took up, surface water and absorbed water, was approximately 1 per cent.—practically nothing. In the case of a piece of hard quartz it would not exceed 0.3 per cent., or less than $\frac{1}{4}$ per cent. That of course meant an extremely small quantity. The ore first came out of the mine as wet as it could be. It might remain for a few days or a week, during which time it was exposed to the dry atmosphere, and consequently a great deal of the moisture would be removed. But even supposing that it came to the mill wet, what happened? First it went into the stone-breaker to be crushed. The surfaces of the stone were exposed to the moisture, and took it up. It was then probably elevated and went to the grizzly, then to a second breaker, and to a screen. During all that time there was a current of air. A part of their system that he had not mentioned being that there was a fan to exhaust the fine dust. By the time the ore got to the first screen, before the rolls, the moisture, even if originally there were 5 or 6 per cent., did not then make any difference. As a matter of fact, there were very few mines in the world in which the ore was anything like as wet as that. It might look wet. He had taken a very bad sample of ore, a very porous piece, and the most that it would take up was 0.2 per cent. by weight. There was another point in which he thought the Author was mistaken. He wished to limit the use, not only of Krom rolls, but of all dry-crushing machines, to cases where the after process of concentration or amalgamation was to be a dry process. He (Mr. Western) could not in the least understand how the Author could arrive at such a conclusion. In all mills the ore was more or less dry to begin with. Water had to be mixed with it, if it was to be treated by the wet process after it was crushed. In the case of the stamp battery, the water was put into the battery box, and there mixed with ore and made into pulp. Any mechanical engineer would say that that was the most unmechanical mixer that could possibly be invented. Water was put into the battery box not for the purpose

Mr. Western. of mixing, but really in order to carry the ore out. Everybody knew how inconvenient dry stamping was; they could not get the ore out of the box; they could pulverize it, but they could not get it away. Somebody had thought that it was a good idea to put water in, because it would assist in carrying it out. It did so. The water was dashed against the battery screen; the ore was carried through the screen and got out. What objection could there be to taking the dry ore from whatever machine it might be pulverized, and to placing it into a properly designed mixer? It was there mixed and made into a pulp exactly of the same consistency except that there was not the same large quantity of slime. From that specially and properly designed mixer they could feed the stream of pulp in precisely the same manner as if it went over the lip of the battery box.

Mr. O'Driscoll. MR. FLORENCE O'DRISCOLL said it was a difficult matter to speak on the subject of the reduction of gold ores without referring to their subsequent treatment, by amalgamation and concentration, because, as a matter of fact, crushing was simply a means to an end. If the crushing was well done, the end was simplified; if it was badly done, the difficulties of subsequently saving the metallic contents were greatly enhanced. Strictly speaking he hardly saw how crushing, amalgamating and concentration, preparatory to subsequent treatment could be considered and discussed as separate subjects, without the relationship between them being considered. With a view to the most successful saving of the metallic contents of an ore, the ideal crusher was one which would liberate every particle of metal or pyrites without destroying their grain, and deliver the whole product, gangue, metals and pyrites of a uniform size, so as to render the amalgamation and concentration of the richer portions more easy. When he used the term pyrites, he meant to include sulphides, arsenides and other compounds commonly grouped together and spoken of as pyrites. The primary necessity was, of course, to crush the ore, but while doing so, the ultimate object, namely, to save the metallic contents, should never be lost sight of. If it were simply desired to reduce quartz to powder, the machine which worked cheapest and quickest was the best. The conclusion had been forced upon him that, varying according to the circumstances of the cases and the ends in view, all the generally accepted methods of crushing quartz might be called good. Some men simply desired to get a large output of pulverized material at a cheap rate; others regarded more the character of the product than the actual quantity of the output. As far as he knew in all classes of auriferous quartz, the portions

containing the metal were the softest. When stamping, rolling, Mr. O'Driscoll. or grinding quartz, those softer portions obviously were the first to become small. The great point to be observed was to remove at once that which was sufficiently fine, or else the reduction of the hard quartz, continuing while those softer portions were present, reduced them to a condition in which the difficulties of subsequent treatment were considerably enhanced. With regard to stamp mills: as a rule each stamp weighed from $7\frac{1}{2}$ to 9 cwt., and had a shoe about 8 inches or more across the face. Usually the height of the drop varied from 6 to 9 inches. It stood to reason that such a contrivance, however excellent it might be to reduce quartz to powder, had the effect of not only cracking the shell of quartz, but also reducing into impalpable powder the kernel which they were so desirous of saving. Steam-stamps, with great wide shoes that struck an enormous blow, pulverized quartz very rapidly, but the metal contents and the pyrites were also either made quite flat and cut into small pieces or reduced to atoms. It was, of course, easy to understand why the product was very uneven in size, when two or three materials of different hardness and toughness were all receiving the same amount of pounding. With all machines he knew, the product was more or less uneven, but the machine which broke the ore fine, and allowed it to escape, before the softer portions were ground into impalpable powder, gave the best result for after treatment. He had lately seen some fast-running light stamps, weighing something between 2 and 3 cwt., with a shoe of about 4 inches at most across the face, which gave a very much better product for subsequent treatment than the heavy-striking wide-faced stamp. With the latter, when the soft material was pulverized, it had not time to get out between the shoe and the die before the stamp came down upon it with the next blow. It entirely depended upon the characteristics of individual ores what arrangement of machinery was most suitable for their treatment. Broadly speaking, he knew of no cases where stone-breakers might not be introduced with the greatest advantage. From the stone-breakers there should be an automatic series of trommels and screens dividing the product into sizes, some going to other stone-breakers delivering smaller products, other products going to rolls, and all the comparatively fine material going to fast-running light stamps with small-faced shoes, or to Huntington mills, or to some other machine suitable to the characteristics of the ore under treatment. If much clean metal was present, it was a bad thing to pound it; in such a case, a machine with a grinding action made subsequent gold-saving more easy. Arrangements

Mr. O'Driscoll. should be made at every stage of the work to remove at once to classifiers all ore which had been pulverized sufficiently fine, and it would be found that, even from the preliminary stone-breaker there was a proportion of this fine ore. The easiest way to carry out this moving of the ore from place to place was by streams of water flowing through the mill, and he knew of no system of conveying ore so well and cheaply, and also of subsequent classification and concentration, as by working in the wet way. He agreed with the Author that for argillaceous, brittle, and soft gold quartz, Huntington mills were excellent machines, but to get any satisfactory result with them, they had to be worked in conjunction with stone-breakers, breaking fine, and delivering into an automatic feeder, intelligently regulated to the capacity of the mill, according to the particular ore it was working upon, otherwise everything went wrong; there was heavy wear and tear, breakages, bad products, and soon the mill was passed aside as worthless. He had seen cases also of ores containing much decomposing sulphides where the water used very soon became highly acidulated; the corrosive action on the mill caused it to go to pieces in a very short time. In cases where water from the mine was used, and it was bad for all machines, he should not personally recommend Huntington mills, or machines of that type. Up to the present, the gravitation stamp was the most popular machine for pulverizing gold ore, notwithstanding its theoretical and practical disadvantages; and, as far as he could see, it was likely to continue so for some time, chiefly, he believed, because there was no mill in the market which would stand the same amount of wear and tear, resulting in less breakages and stoppages. Usually the treatment these mills were subjected to was simply villainous. He would now refer to the ordinary small mill, owned by a few miners, which was generally to be met with on gold fields in all parts of the world. Of course it was different with large mills owned by rich men or private syndicates or public companies, who could afford to and did engage the best available talent to design, erect, and manage their mills. Those small mills generally consisted of five or ten head of stamps, a few feet of copper plates for amalgamation, and strips of blankets or hides for concentration, or a few feet of narrow wooden troughs, with little strips of wood nailed across the bottoms to make a ripple in the water and cause the pyrites to fall down. The ore was brought in trucks or carts into the mill, and tipped on a platform where a labourer stood, whose tools were a sledge-hammer and a shovel. The sledge-hammer was there

nominally to be used for breaking up the large lumps of quartz Mr. O'Driscoll.
—the shovel was for feeding the battery. Generally the man found it easier to work with a shovel than with a sledge-hammer, so he mostly rolled the lumps into the battery, and shovelled in the fine stuff. Perhaps his mate at the engine or somewhere else in the mill, wanted him, or he wished to talk to some one, so, after choking the battery up with stuff, he would go off and leave it. Presently it would begin to sing out—in other words, to run empty, with the shoes banging on the bare dies. Then the feeder would come back to his work and fill it up again: or, even if he never left his stand, the feeding system was most irregular. Looking at the result of such work, it was not to be wondered at that men would say the product from a stamp battery was not in a good condition for subsequent treatment. As a rule, there was no trouble taken to ascertain the most suitable class of mill to erect for the treatment of the particular ore in view. He would even go further and say, generally speaking, there was no trouble taken to find the percentages of metal saved and lost. He could give many instances of this which were almost laughable. When he visited, some time back, the mill working the ore of one of the Australian mines best known in the London market, he spoke to the manager, who was a most intelligent man. He, unfortunately, was not an assayer, and his directors did not see the advantage of employing one. He did not know the average contents of the ore coming from the mine, nor did he know the amount lost, nor did any of the directors. He only knew they grumbled when the returns did not keep up to the average, and were satisfied when they did. Those returns, of course, almost entirely depended upon the quality of the ore coming from the mine, the system of treatment being an unvarying one. Again, at one of the best known old Australian mines, which had paid over £1,000,000 in dividends, no concentrating machinery was used, although two or three sets of men were working on their refuse further down the creek, and the first man had actually made a fortune, and was retiring from work, by simply saving the free gold that they had lost, without attempting to save or to treat the pyrites, worth £16 or £18 per ton, which escaped in quantities. When men acted in that way, as they very commonly did, it was hardly reasonable to expect they would trouble themselves about such minor details as a suitable crushing machine. There were one or two small points in the Author's Paper with which they were not in agreement, and those he would only refer to briefly, as they were perhaps clerical errors. In reference to the statement in re-

Mr. O'Driscoll. gard to auriferous amalgamation, it was a fact that in ordinary practice the amalgam was generally wiped off the plates three or four times daily. When there was much gold in the ore it was frequently done every two hours or so. There was generally a weekly or fortnightly clean up, when the amalgam was taken out of the ripples and wells, and the magnet drawings removed from it. These were sometimes very rich in mechanically caught gold. Fresh mercury was put into the ripples, but the plates were rarely scraped unless in a "customs" mill, when the ore from one mine had been finished before another was being put through. The plates generally amalgamated better when there was an amalgam on them than if clean. With regard to the statement as to the subsequent treatment of ores by potassium cyanide, chlorine, etc., as far as he knew the object of using cyanides as solvents was to obviate the necessity of roasting, and he knew of no instance where ores were roasted prior to being treated by cyanides. With reference to the statement, as to the friction of the cam making "the stamp partially rotate about its axis, this motion inducing a grinding as well as a crushing effect upon the material under treatment." Within the limits of his (Mr. O'Driscoll's) observation, the stamp was rotated while being lifted by the cam, and he had not noticed an instance of where there was any grinding between the shoe and die, which was given by the twisting caused by the cam. The Author had referred to the steam-stamps producing less sliming than the ordinary gravitation stamp. Mr. O'Driscoll had already expressed the view that the heavy stamp intensified the sliming evils caused by the ordinary gravitation stamp.

Mr. Imray. Mr. JOHN IMRAY said that to the Author's very able and interesting Paper he might, perhaps, be allowed to add two items from his own experience which bore a little upon the history of gold-reduction machinery. About thirty-five years ago an American brought to England a machine for pulverizing quartz and other minerals. That machine had a great reputation at the time, and a large company was formed to work it. Mr. Imray had a contract for making the machinery, and he saw it while it was in operation. The machine consisted of a basin which revolved upon an axis inclining about 60° to the horizon. In that basin there were a large ball and a small ball. The material put into the basin was crushed by the revolution of the basin. It was curious that for some time any material that might be put in, even street scrapings, produced gold; and a large sum was consequently paid for the patent. But it was very soon discovered that unless the patentee was

present no gold was got out of the scrapings. The result was, Mr. Imray. the company soon broke up, and the machinery was returned to his factory to be broken up for scrap. Two years after that, Mr. Bashley Britten invented an excellent gold-quartz pulverizer. It consisted of a stationary basin, rather deep, with a hemispherical recess in the centre of its base, and in that basin a very heavy pear-shaped body was caused to rotate, rubbing itself upon the sides of the basin, while the point of the pear, which was spherical, revolved in the recess below in the midst of a charge of mercury. This was worked at his factory several times. He obtained some gold ore from Australia, and the machine extracted the gold very completely, so much so that it was reckoned by careful assay that only about 3 per cent. of the gold was left in the tailings. Mr. Britten took some of the machines to Australia, where they did very good service, and he heard, curiously enough, the other day—some thirty years after—that one of them was working, and working well yet.

Mr. H. GRAHAM HARRIS said the Author of the Paper having supplemented what he had written by some slight mention of the Crawford machine, which Mr. Harris had been engaged for about three months last year in testing, in conjunction with Mr. Sellon, of Messrs. Johnson, Matthey and Co., and Mr. Hurlbutt, of Messrs. John Taylor and Sons, he should like to say a word or two upon it. The last machine described by Mr. Imray was very similar to the Crawford machine. The latter consisted of a circular basin or trough hemispherical in cross section. This circular trough was divided vertically and circumferentially, the outer portion being fixed; whilst the inner portion, having a circular spindle passing up through it, was capable of being revolved (Fig. 25). In the circular trough were placed eight chilled cast-iron balls. The trough was about 4 feet in diameter, the balls about 8 inches in diameter. The number of balls placed in the trough was not sufficient to occupy its whole circumference; as a fact, ten could be got in, but eight only were used. The whole machine had a cover secured to the outer fixed portion of the circular trough, with a central feed-hopper. Below the vertical division of the trough there was another vessel, in which the mercury for amalgamation was placed; the ore, having been previously crushed to the size of a small nut in a Blake machine, was fed into the hopper through the hopper, and the central spindle, carrying with it the inner half of the hemispherical trough, was revolved, the speed being about 180 revolutions per minute. This caused the 8-inch chilled cast-iron balls to revolve each on its own

Mr. Harris.

Mr. Harris. axis, and all of them around the circular trough, and the ore, coming in contact with and between them and the fixed basin, was ground to a fine powder. A feeble current of water was passed into the bottom of the machine, and passing over the surface of the mercury up through the vertical division in the circular trough, through the ore which was being crushed, overflowed at the top through openings in the side of the fixed feeding-hopper. The leading idea of the machine was, that as the ore was crushed sufficiently fine, it would rise and pass away with the current of water, and that the particles of gold, being heavier than the particles of crushed ore, would not be so carried away with this current of water, but would pass down through the vertical division in the circular trough, come in contact with the mercury, and be amalgamated there. The current of water in leaving the machine would, as would be seen, pass over the surface of the mercury, thus, as it was claimed, keeping that surface clean, and in a condition to readily amalgamate with the gold. It was an extremely ingenious machine of the greatest possible simplicity, and there was no doubt that, as a mechanical grinder for ore, it was an extremely successful machine. What had been its subsequent fate Mr. Harris could not say. During the trials, altogether something like 300 tons of ore were passed through machines of this type, the ore being obtained from mines in all parts of the world, and varying as much as possible in character. His opinion was, as the result of these trials, that probably no machine could possibly be equally successful in dealing with all classes of ore, as these varied so much in their nature.

Prof. Foster. Professor C. LE NEVE FOSTER said that the Author had begun by saying that gold was found in deposits in three conditions, which he divided into gold in the native state, gold chemically combined, and the vague class of ores containing pyrites. In the Paper the Author stated that he considered the gold in that class to be in a state of mechanical mixture, and not in a state of chemical combination; it would, therefore, have been more logical to have made the division into two classes, (1) ores containing the native gold, and (2) ores containing gold chemically combined with some other element, and then to have subdivided the first class into two, one containing little or no pyrites, and the other containing a great deal. He had given no lines of demarcation between these two subdivisions; in fact, no such line existed. He quite agreed that in the pyrites class the gold did exist very frequently in the native state. Secondly, the Author stated: "Should the percentage of pyrites be large, the amalgamation process will

fail to separate the free gold of the ore owing to the sickening of the mercury." On that point he was not at one with the Author. He had found that in treating ores containing as much as 20 per cent. of pyrites (which he thought the Author would admit was a fairly large percentage) one could extract from 70 to 90 per cent. of the gold simply by amalgamation in the improved arrastras known as Francfort mills. That was being regularly done year after year in Italy, and thousands of tons were being so treated. The result in 1890 was that, on an average, 79·4 per cent. of gold was extracted from pyrites ore of that kind. If the Author desired instances of a larger amount of pyrites, he might mention the gold mine in the Val Antigoria, near the Domodossola. In that mine they had had as much as 50 per cent. of pyrites, and 80 per cent. of the gold had been taken out by the amalgamation process. The question of sickening mercury also deserved some comment. He did not agree with the Author that the sickening was due to the pyrites as such; he thought it was due indirectly to the pyrites but not directly—indirectly owing to the formation of sulphate of iron. It was the sulphate of iron, produced by the decomposition of pyrites, that did the mischief. He based that opinion on two facts. First, it was found that by the addition of a small quantity of lime to the ore, allowing the ore to remain in contact with the lime for twenty-four hours, they could often considerably reduce the loss of mercury. Secondly, he well recollected making the experiment of concentrating some ore by jigging and then amalgamating the concentrated ore with mercury; and he had found that the concentrated ore containing a much larger percentage of pyrites than the original ore was amalgamated with a smaller loss of mercury. With reference to the Gates ore-crusher, the Author had said that there was a considerable prejudice in this country against it. He (Dr. Le Neve Foster) did not think he was justified in that statement. He did not think it was a case of prejudice. Mining engineers had the Blake crusher, which did its work excellently, and gave them what they wanted. It was a machine whose parts were quite as durable as those of the Gates breaker, and why should they throw aside a Blake crusher that was in use, and recommend a Gates crusher in place of it, if they knew that the former was doing well, and if they found that the latter was more expensive and more complicated? With regard to Cornish rolls, he thought that the Author in calling them a primitive machine had used that term somewhat slightly. Primitiveness in a machine was often from a miner's point of view a merit—a positive advantage. Every one would admit that the Krom rolls

Prof. Foster. formed an advance upon the Cornish rolls. When the Author mentioned some statistics indicating the durability of the tires of these rolls, he might have added a note stating where those statistics could be found. Probably they were statistics in the possession of many present, but it would be convenient to know exactly where they occurred. It was possibly in a paper published in the Transactions of the American Institute of Mining Engineers. The Author also added, "In gold-quartz dry-crushing operations the very fine dust which is inevitably produced in greater or smaller quantity, according to the character of the rock, and which is unlikely to carry with it any estimable quantity of gold." He did not think that the very fine dust would invariably be as poor as supposed. Having made some experiments passing a certain sample of crushed ore through sieves of different kinds, he found that the finer the ore the richer it was in gold. It was true he only went down to a sieve as fine as twenty holes to the inch. A few days since a sample was tried for him by Mr. Clarkson, and he found with an ore containing 16 dwts. to the ton, that the portion that went through one hundred and twenty holes to the lineal inch was richer than the original ore. It contained 1 ounce and 6 dwts. to the ton instead of 16 dwts.; but in this case the assays referred to gold and silver together, for the gold had not been determined separately. Those were two instances which tended to show that the finest dust might not always be poor enough to be neglected. He was rather surprised to find a statement that "Stamps appear to have had their origin in Cornwall, where they were used at least as far back as the seventeenth century." This proved that the Author had not perused that delightful old work of Agricola. As it was written in Latin one might not be able to read it in the original; but at all events there was the old German translation, and if the text was not intelligible to all, there were the beautiful old wood-cuts in the book published in the middle of the sixteenth century, giving magnificent illustrations of stamps. He thought it far more likely that stamps were introduced into Cornwall from Germany than that they were invented in Cornwall. With reference to the Husband stamps, which in an instance that came to his notice were being driven at the rate of one hundred and forty blows a minute, the objection made was that they required so much lubrication on account of the speed, that the oil and grease were thrown about, and interfered with the plates which had to catch the gold. The Author had used the expression "steam-stamp." "Steam-stamps" conveyed to a great many people the idea simply of stamps worked by a steam-

engine in contradistinction to stamps worked by a water-wheel. Prof. Foster. He preferred the word "steam-hammer stamp," in order to make it plain what was intended. In referring to the "Wheeler pan," the Author spoke of the use of steam for heating the water. He (Dr. Le Neve Foster) rather questioned the necessity of that heating, because the friction of the runner upon the bed produced a great deal of heat at the very point that it was required, if it was required, viz., where the ore was lying in contact with the mercury. The heat was so great that whilst a mill was being cleaned out he had seen the pyrites taking fire on the bed. In proof that heated water was not necessary he would mention his experience in Italy. For a long time he took careful observation of the temperature of the water supplied to the mills, and had compared their duty, i.e., the percentage of gold extracted, in the winter months with their duty in the summer months; and in the year 1869-70 he obtained the following results:—The average temperature of water supplied to the mill during the six summer months was 52° Fahrenheit. The average temperature of the water supplied in the winter months was 39·4° Fahrenheit; and yet in spite of that, and in spite of the average temperature, for instance, of the month of January, 1870, being as low as 33·6° Fahrenheit, they extracted 3·1 per cent. more gold with the cold water than with the warm. It might seem from that that cold water was better for amalgamation than warm water; but other matters had to be taken into consideration. One possible explanation was this—that in the summer pyrites would be more likely to decompose, and there might be loss, owing to the decomposition of the pyrites and the sickening of the mercury. The important point, however, was the fact that in the summer the water was turbid. It came down from the glaciers at Monte Rosa and was turbid, owing to the movement of the glaciers being greater in the summer than in winter; in winter, when the glaciers moved slowly, they had clear water. These figures did not therefore prove that cold water was better—they simply showed that amalgamation was possible, even when the temperature of the water was on an average as low as 39°. It might be interesting to quote the actual cost of gold-crushing at almost the only gold mine in the kingdom—the Morgan Mine in North Wales. He received the figures two or three days since, and his friend, Mr. N. T. Williams, the manager, had allowed him to state them publicly. During the year 1891, the average cost of mining the quartz, including explosives, timbering, and tramming in the mine, was 6s. 6d. a ton; cost of tramming quartz to the mill, 6½d.; milling, when done by water power, cost only

Prof. Foster. 10*d.*, but when done by steam power 2*s.* 2*d.*, and the average for the year was 1*s.* 5*d.* a ton, on an output of 13,802 tons of quartz, producing 3,462½ ounces of gold, or at the rate of 5½ pennyweights per ton. In conclusion, he was grateful to the Author for having put so much information into the Paper, and for having offered useful criticisms concerning the machines he described.

Mr. Clarkson. Mr. THOMAS CLARKSON said that with reference to the finer reducing, taking up the work where the stone-breaker stopped, there were very few good machines. He entirely agreed with the Author in his recommendation of Krom rolls, the product being much more uniform, and the percentage of slime very much less, than in other machines doing similar work. The Author had enumerated the objections to the Blake machine, and had pointed out that the work was only done during the forward stroke. So far, however, from that being a defect, many considered it an advantage, as giving the machine a chance of recovering itself during the back stroke. The other objection was surprising—that the product was not uniform, but of various sizes. Surely they were all aware that no pulverizer or crusher could possibly produce stuff of uniform size. That was simply an ideal; but it was a question of great importance to find out how nearly they could approach to it, and he was glad for that reason that the question had arisen. The reduction of ores was, of course, totally different from that of cement. In the former case, all that was necessary or advisable was to detach the metallic mineral from the matrix, and preserve it as much as possible large and granular, whereas in the latter case they wanted as much flour as possible. The question of uniformity of size not only affected the wear and tear of the machine, and its capacity, but also, as Mr. O'Driscoll had pointed out, the subsequent process of extraction. Few determinations appeared to have been made of the proportion of various sizes in an ore that had been reduced to a given mesh. He might cite two or three cases from a great many experiments he had made on the subject. In the first case, by the Krom rolls, the ore was reduced to pass through a 40 mesh, and 39 per cent. by weight passed through 120. In the second case, the ore consisted of white quartz, containing auriferous pyrites, 6½ per cent. residue remained on a 20 mesh, and 50 per cent. by weight passed through 120. In another case, that of a very friable ore, from 32 to 33 per cent. of slimes were produced; and it was noteworthy that the slime carried from 57 to 60 per cent. of the gold in the ore. He had frequently proved that a large quantity of gold was contained in the fine slime, and he was certain that much of it was lost in any wet

treatment. The only way to save it was to crush dry. In regard Mr. Clarkson. to the solution of the problem of getting a uniform product, designers of machines would have to consider not only the efficiency of single machines, but also the efficient grouping of machines. In other words, as Mr. Western had pointed out, the reduction must be done in stages. Instead of attempting to do it in two stages, as was the case generally, there should be from twice to three times that number, and after each operation the stuff, sufficiently finely reduced, should be completely removed before the remainder was passed on. He thought the greatest improvements in the future might be expected from a development of that principle of gradual reduction.

Mr. OSCAR GUTTMANN said that the origin of stamp mills was Mr. Guttman. probably due to the gunpowder manufacture. In 1340 a stamp mill existed at Augsburg, and Conrad Harscher, of Nuremberg, owned one in 1435. In 1692 there were twenty-two in existence in France alone.

Mr. BENNETT H. BROUGH said that the stamp mill, like so many Mr. Brough. other appliances with which they were familiar, was "made in Germany." It was introduced in the mines of the Hartz about the year 1500. It was doubtful who invented it, but it appeared from written records that in 1529 a stamp mill was erected at a mine near Clausthal, in the Hartz, by an assay-master named Peter Phillipp. It was, of course, very primitive, and consisted merely of a stamp raised by a couple of levers attached to a wheel. It was found that the use of the machine produced so much dust that the health of the workmen was affected, and it was consequently abandoned. But the inventive genius of the Hartz miners continued to work on the subject, and in 1570 Simon Krug and Nickel Klaerer erected a wet stamping mill. On the authority of Dr. Gurlt, a well-known German writer on mining matters, it was stated that a stamp battery was introduced in the Saxon mines in the year 1507 by Sigismund von Maltitz; but he had been unable to find Dr. Gurlt's authority for that statement. It undoubtedly appeared, however, from an old chronicle, that a wet stamp battery was erected at a mine in Joachimsthal in 1520. The curious working drawings of stamp batteries, referred to by Professor Le Neve Foster, published in Agricola's book in 1556—the oldest systematic mining treatise in existence—showed that they were exactly the same as stamp batteries now seen here and there in Cornwall and on the Continent. Of course one could not help comparing such primitive machines with the wonderful steam-stamps in the Lake Superior district for treating copper ores. But

Mr. Brough. those stamps in their time certainly did very good work. He had seen in some of the Hungarian mines some primitive stamps almost exactly the same as Agricola's, weighing only 100 lbs., and with stamp heads made in some cases of hard blocks of quartzite, still in use, and, in cases where the conditions of water-supply were favourable, well able to treat with profit an ore containing as little as $2\frac{1}{2}$ ounces of gold to 50 tons of ore; and, in fact, at Zell, in the Tyrol, they were able to treat a slaty material containing 1 ounce of gold to 50 tons of ore. Going back still further, it was found that even in very ancient times gold-quartz reduction was done with considerable care. Diodorus Siculus, the Greek historian, writing 1,900 years ago, gave a very accurate account of gold-quartz reduction in the mines of Upper Egypt. The ore, in his time, was first coarsely crushed in mortars, and subsequently finely crushed in hand-mills resembling the flour mills of the present day. In Mexico, in the olden times, the miners were able to get with the rude arrastra three times as much gold from a given ore as subsequent workers had been able to get with the very best forms of modern machinery. Of course it would be gratuitous folly to urge that the old arrastra, with its limited output, should be reintroduced; still, he could not help thinking that the greatest success would attend that machine for gold-quartz reduction which imitated most closely the rubbing and burnishing action of the ancient primitive arrastra.

Mr. Neate. Mr. PERCY J. NEATE said he noticed an old friend in the Bryan Roller Quartz-Mill. Very many forms of that type had been designed. He had laid upon the library table an interesting old specification dated 1852, which anticipated very many later so-called inventions. He also showed details of one of the latest developments of edge-runner grinding, which very fairly met the Author's criticisms, though the general arrangement would doubtless have to be modified for export. The chief point noticeable was that the runners were inclined inwards, until the centrifugal force, at the pre-determined speed, exactly balanced the tendency to fall inwards, relieving the end collars of all wear and tear. He was now engaged in experimenting with a modification of this mill for dry grinding, in which greater speed and portability would be attainable. In mills such as the Huntington, speed of revolution was of the utmost importance, as the grinding capacity, other conditions being equal, varied as the cube of the number of revolutions per minute. The mention of the Sturtevant mill called to mind an interesting experiment which he had been told was once tried with that machine. Both revolving heads

were rotated at their usual speed, but in the same direction, Mr. Neata. the mill usually being run with the heads in the opposite direction. The output was found to be scarcely affected by the change. The obvious explanation was that the grinding was really done by flinging the pieces against the outer casing of the mill far more than by their mutual collision, this condition of things practically wiping out their claim for greater resistance to wear and tear than the ordinary form of disintegrator. He had seen experiments tried with the Sturtevant mill on rock phosphates in which it was clearly proved that the mill was not suitable for fine reduction, and all pieces under $\frac{3}{8}$ inch cube were thenceforth sifted out from the mill products and separately ground by millstones. The Adair Cruickshank process, though comparatively new, promised very well where an extremely fine grinder was required. It was essentially a process for the treatment of spent tailings, and consisted of subjecting these to the action of what at first sight might be taken for ordinary millstones, circular disks on a vertical axis, the lower one rotating. Each disk was armed with a series of hard metal blades of peculiar spiral form, which could best be understood by viewing the wooden patterns and model mill shown in the library. Metal disks had long been used for the purpose, but owing to the greater speed at the circumference the wear was concentrated there, and the faces soon became convex, with the result that the entrance of the feed was blocked and very large particles escaped grinding altogether. In an Adair millstone the spiral blades were made to touch each other on their outer edges, but were much thinned on their inner edges; consequently the actual wearing surface was correspondingly reduced near the inner circumference of the ring, which was thus enabled to wear hollow and attack the pieces in order of their size much after the fashion of the Gates crusher. About a year and a half ago he made and sent to Johannesburg three 4 ft. 6 in. mills of that type which gave excellent results. He was informed by Mr. Adair that the following results had been attained upon a sample of tailings thought not to be worth further trouble. Each mill ground $1\frac{1}{2}$ ton per hour to 90 per cent. through a $90 \times 90 = 8,100$ mesh, with an average indicated HP. of 18 or under $14\frac{1}{2}$ indicated HP. per ton. The speed was 100 to 125 revolutions per minute, and the wear was 5 lbs. of rough cast blades per ton ground. The tailings treated assayed, 9 dwts. 3 grains; gold returned, 5 dwts.; absorbed by plates, 1 dwt.; blankettings, $1\frac{1}{2}$ dwt.; spent tailings, $1\frac{1}{2}$ dwt.; in the last item the slimes being small in bulk assayed 5 dwts. 13 grains and the sand only

Mr. Neate. 15 grains. He might mention that about ten years ago a German firm, Messrs. Naegel and Kemp, who seemed to lead the way in grinding-machinery, sent to this country a set of rollers with separators or sifters, very similar to the arrangement described as the Krom rolls. They were for grinding Portland cement, but the principle was essentially the same; that of treating the material between gradually diminishing spaces, and each time removing the flour as far as possible. It did not answer very well for Portland cement, because the very quality essential in gold-mining was not essential but actually deleterious in grinding cement, namely, that the pieces were of too uniform a size, and although the machine appeared to grind very fine, it gave comparatively little impalpable powder.

Mr. Cox. Mr. S. HERBERT COX said he agreed in the main with the Author's conclusions, more especially as to the fact that the Krom rolls, the gravitation-stamps, and the Huntington mills might be looked upon as the only machines which hitherto had stood the test of time. But he thought that the Author had hardly given the stamps fair treatment. There could be little doubt that the Krom rolls were the best machines yet made for dry crushing, and it was possible, as Mr. Western had suggested, that they might be used for dry crushing even when subsequent wet treatment had to be adopted. But apart from that, the stamp-batteries and the Huntington mills had been compared, and he thought that that comparison, as it had been instituted, was hardly fair to the stamps used. It was very difficult indeed to compare the actual results obtained by those two different machines. But while the actual HP. required to drive the stamps was mentioned, only the nominal HP. required for the Huntington mills was taken into consideration. He knew numbers of instances in which a twenty-head battery was worked with a 20 nominal HP. engine; that engine was also driving a stone-breaker for supplying the battery, and in one case he remembered also working eight Frue vanners. Of course they required very little power indeed, and one need hardly take it into consideration. But it was now claimed by the Author, and by manufacturers, that a 5-foot Huntington mill was equivalent to a 10-head stamp battery; but at the same time it was only claimed that a 5-foot Huntington mill would pulverize 20 tons of ore in twenty-four hours. That, he assumed, was through a number 8 or 35-mesh screen. A well-built stamp battery would pulverize at least $2\frac{1}{2}$ tons a head of medium hard rock per twenty-four hours, if it was properly built and worked with a stone-breaker at the back, and with self-feeders as

well. When, therefore, they came to a question of comparison of the two machines, they had to take into consideration the amount of ore that could be put through. They might say, at any rate, that the stamp-battery would put through at least 25 per cent. more than the Huntington mill, and although there was no doubt that it took a little more power to drive, still that extra power was well expended in getting the work done in a more satisfactory and efficient manner. Then, again, there were other points in connection with these two classes of machines. It was claimed, and of course it was perfectly true, that the Huntington mill had less first cost than the stamp-battery; but when they took the whole plant into consideration, and came to include the whole arrangements, the building the mills were enclosed in, the hoppers that had to feed the mills, and the construction generally, the difference between the first cost of the Huntington mills and the stamp-batteries was not relatively so much as one would suppose from the Author's Table. Then there was another point, viz., that the Author stated that the Huntington mill would save in the mill itself 70 per cent. of the free gold. He must have only had to deal with very coarse gold if that had been his experience. He (Mr. Cox) had seen a Huntington mill run with different classes of ores by the same man, and in one case he had seen a saving of 90 per cent. of gold in the mill, and in another case 5 per cent. These variations were constantly occurring. There was the same variation in the quantity of gold saved in the boxes of the stamps. They might sometimes save a large proportion of gold in the box where the gold was coarse; but if it was fine it would come outside and would have to be saved on the plates or by some other mechanical means. Taking everything into consideration, he thought he expressed the opinion of most practical men in saying that gravitation-stamps were the best and the most efficient machines at present in use, and that it would really be difficult to supplant them. In most other respects he cordially agreed with the Author in his conclusions, but he might point out that in a great number of instances the Huntington mills had been put up at mines and had not worked satisfactorily. The Author had stated in regard to the Huntington mills that the cost per ton of crushing, due to the wear of the ring dies and rollers, was only 2½d. That, of course, was taking the price of ring dies and rollers in England. It should be remembered that they had to go from England to foreign places and afterwards to the mines, and the actual expenditure thus incurred increased the price very much. In Sydney it was generally considered that the wear of ring dies and rollers

Mr. Cox.

Mr. Cox. represented at least 6*d.* a ton. He imagined that the actual wear on the Huntington mills and the stamps would be much the same. At the same time the danger of breakages in the Huntington mills was much more important than in the case of stamp batteries. If a ring die broke—he had known them break two or three times—it meant a considerable expense and considerable delay in repairs.

Mr. Giles. Mr. GILES, Vice-President, in opening the adjourned discussion, said the Paper on "Gold-Quartz Reduction" was one upon which discussion was desirable from the mining, mechanical, and scientific points of view. When it was known that in Africa alone the mining industry was producing upwards of £4,000,000 of gold every year, a production which was certain to increase very considerably, it would be admitted that it was a Paper which should not be passed over lightly.

Prof. Roberts-Austen.

Professor W. C. ROBERTS-AUSTEN said people were rather in the habit of thinking that the question of quartz "reduction" belonged more to the miner than to the metallurgist, and the Author specially deprecated discussion on the metallurgical side of the question. The Author had gained his experience in a very hard school—the African gold-fields—and it was to be hoped that his experience in those fields, where he really did excellent service, would be laid before the Institution in a subsequent Paper, so that the metallurgical side of the question might be discussed. Of course quartz-reduction did not mean the division of quartz into fine particles. It was very difficult to discuss the question apart from metallurgy; for instance, although there could be little question that gold did usually occur between the cleavage planes of sulphides as metallic gold, there were undoubtedly cases which should not be ignored, in which the precious metal occurred as a sulphide, soluble in another sulphide, and this question ought to receive due attention. He wished to refer also to the material used in all these mechanical appliances. The Author stated that certain rolls were made of the best open-hearth steel. Open-hearth steel was, generally speaking, a mild steel, and did not possess anything like the hardness of chilled iron, which had proved to be very useful, as had tough wrought iron. They wanted a material which should not be excessively hard. The conditions were somewhat the same as in the manufacture of dies for ordinary coinage-purposes; they required a material which should not be broken by impact, but at the same time should show neither any signs of deformation by blows of the coining press, nor attrition by the impact of fragments of quartz. It

seemed, therefore, that the question as to the material to be used for rolls and stamps was very much one for the metallurgist. He was quite aware that the conditions to be met with in these appliances, some with abrading-surfaces, and others in which the kind of blow imparted was of paramount importance, were widely different from those which prevailed when a shot had to penetrate a steel plate. It was perfectly easy for the metallurgist to give the military engineer a material which should be extremely hard; the addition of chromium, for instance, would meet that case. But what the miner needed, and it was for the metallurgist to attend to this, was a material which should be extremely tough. He could not help thinking that some of the varieties of Hadfield steel, or some alloy of iron in which tungsten was introduced, would render admirable service in the future. With regard to the speed of rolls, he could have wished that the Author had made references to current literature. There were valuable Papers on the production of gold and silver in the United States, published by successive Masters of the Mint, and amongst them, in 1880-1, there was an admirable Paper on quartz reduction, by Mr. J. Richards, which the Author might consult with advantage, if he had not already done so. As to the speed of rolls, it must be remembered that the line of action in a pair of rolls was really very limited, and it might be of importance to consider, not the velocity of the rolls themselves, but their angular velocity, the rate at which the two crushing surfaces approached each other. Hence it had been found, by careful observation, that the rate of a jaw breaker might really outrun that of a pair of revolving rolls. He quite agreed with much that had been said on the excellence of machines following the arrastra type, in which a grinding surface was substituted for a blow. Unquestionably in many cases the short sharp blow of a stamp was far more effective than a heavy blow, because when pellets of gold were submitted to continued impact they were often rendered so hard that mercury would not attack them readily. Chromium had been added to the steel used in the Huntington mill, but with very doubtful success, and he thought that in the future the metallurgist would place at the disposal of the miner some better materials than he had at present.

Prof. Roberts-
Austen.

Mr. H. C. JENKINS said the Author referred in the Appendix to Mr. Jenkins the difficulty of obtaining the approximate cost of crushing with the Huntington mill. It was very difficult to get complete figures and, above all, anything like an average. In the United States

Mr. Jenkins. Mint Report for 1889, p. 119, there happened to be one case given, and one specially favourable for the Huntington mill. The ore had a very soft gangue, slate; 3,400 tons were crushed, and the cost of milling came out at 23·9 cents a ton. The 3,400 tons required twenty-five days to run through, and four mills were used, whilst two men at 3 dollars a day, eight at $1\frac{1}{2}$ dollar, and a foreman at $3\frac{1}{2}$ dollars a day, were required to attend to the operation.

Mr. Woodhouse.

Mr. ALFRED WOODHOUSE said he thought that the information furnished by the Author should prove of great service to engineers generally. The Paper practically divided reduction plant into three heads: first, pulverizing with falling or revolving weights; secondly, by rollers; and thirdly, by centrifugal action. Of course all inventors had an idea that no horse was like their own, but the public generally wished to find out which was the most suitable for practical work. He thought the first object in all reduction plant was summed up in two words, "simplicity with efficiency." The great point to be avoided in all pulverizers was the production of slimes. The oldest appliance known was, of course, the gravitation-stamp, which had proved of great service, and held its own at the present day, because no people were more conservative than miners, and because it could be worked by any ordinary man of intelligence; the repairs were easily attended to, and there was in fact not very much to get out of order. It had a great number of drawbacks; for example, after a particle of quartz had been stamped it did not necessarily follow that it would not be stamped again. The stamper might fall several times on the same particle of stone after it was sufficiently pulverized to escape the screen. Another point was that the stamp was only effective at the point of contact as it fell; while it was being raised there was no effective duty. The only way the ore could be liberated more quickly was by increasing the splash. That could be done in two ways, either by using a steam-hammer or by a pneumatic stamp, or by fixing more stamps of the less weight in one box; for it was the rapid tap and not the heavy crushing blow that broke the quartz. With regard to mills, they were shipped out to various mines (he was speaking of what he had seen), and millmen had no previous opportunity of trying them by the proper method of treatment. They had a feeling of prejudice, and if the thing did not work straight off it was thrown out to rust. The consequence was that, in almost every mining district, any quantity of machinery might be seen, which, if it was properly adjusted, and was not quite so

complicated, would work very well indeed. The fact was that Mr. Woodhouse. millmen would not take the trouble, or they had not had the necessary amount of experience, and failures were due not to the machine but to its manipulation. With reference to the crusher a great deal might be said. It had been practically proved that high-speed crushers not only had a great deal of wear and tear, and were complicated, but they were found not to answer, and consequently they were thrown out. Edge-runners were very slow; they required great horse-power, and had a tendency to push the ore in front of the roll without being crushed. With regard to rollers, as the Author had stated, they perhaps approached as nearly as possible to a proper crusher, because the ore was not crushed a second time, and it gave a fair even grain. The Author had specially recommended the Huntington mill, and the Krom rolls. From his experience, the Huntington mill seemed to him (Mr. Woodhouse) to require skilled workmen. If a piece of iron, or a piece of steel, say a piece of a jumper, got in with the quartz, which was often the case, or if a piece of hard rock got into the mill, there was generally trouble, and the wear and tear was considerable. With reference to the Krom rolls the ore escaped as crushed, and he thought that those rolls or mills generally had a tendency to crush rock in the line of fracture of the crystals. He did not agree with the Author in stating that gold had better be extracted by a dry process if pulverized dry, because it was a mere matter of mechanical appliance to saturate the powdered ore, and treat it with quicksilver. At the same time he would state that, as the Author would perhaps recognise, gold was not easily taken up by quicksilver, unless both the quicksilver and the ore were wet. With reference to American machinery, such as Gates' rock-breakers, and the Fraser and Chalmers stamps, he thought that if the home machinery was equally cheap and effective, as other countries knew so well how to protect their own industries, preference should be given to British manufactures, and that if there was a little more national feeling among engineers, it would stimulate manufacturers to the good of the trade and to the benefit of the mining-industry.

Mr. GEORGE E. COLLINS said that the principal point which had Mr. Collins. struck him, and no doubt many others, was that, in the art of quartz-reduction, they stood to all intents and purposes pretty much where they stood ten years ago. The conclusions which the Author had advanced were substantially the same as those which had been held by other people for some years past, and the figures

Mr. Collins, which he had given did not seem to be the result of his own personal observation. He would greatly deprecate accepting the figures put forward as to output and so forth by the makers of mining-machinery as to their own machines. In many cases which had come under his notice those figures had proved extremely misleading. If they were to take such figures as any criterion as to the value of the respective machines, they would simply put a premium on those makers who were the least scrupulous in their statements. What they really needed was comparative tests of the different machines, with the same ore, and under the same conditions. Such comparative tests, made by trustworthy men, would be practically conclusive, so far as that particular class of ore and those special conditions were concerned. Of course it would be necessary to have the tests on a very considerable scale, and continued for some length of time, because the most important quality in a machine which was intended for ordinary mining-work, generally in a rough country, was that it should stand wear and tear, and that could only be ascertained by having the test on a considerable scale and continued for some time. Such comparative statistics, though extremely desirable, were not easily obtained. The Paper which would really be a valuable guide to mining men in selecting machinery for dealing with a particular class of ore had yet to be written, and before it would be possible to write it, it would be necessary to collect slowly and laboriously a great mass of such comparative statistics as he had indicated. Meanwhile, they had nothing to do but to continue to regard the general consensus of opinion among practical men on the point. That opinion had been fairly stated by the Author in his Paper, except that it seemed to Mr. Collins that most engineers would consider that stamps were suitable for a far greater proportion of cases than the Author would recommend them for. During the past few years a very large number of new machines had been introduced, not one of which had met with any general approval or acceptance, and, so far as he was aware, not one of them was based on any really important new principle, nor was it easy to indicate the direction from which any very important new discovery was to come. On the whole, it appeared to him that they must look forward for an improvement to greater intelligence in the use of the machines they had, rather than to the invention of new ones. Whatever was done, nobody would ever invent a crushing-machine which would not require intelligence and care on the part of the millman; and that was generally where the

failure lay. He thought that in the discussion a great deal too much emphasis had been placed on the necessity for pulverizing to an even size. That, of course, was very important, in some cases, particularly where the gold was contained in sulphides and had to be extracted in the form of concentrates. In dressing ores of non-precious metals careful sizing was all-important, and he was inclined to think that sufficient attention had not been given to it by most American and English engineers; but for the majority of ordinary gold mines what they wanted was simply to crush as efficiently and as cheaply as they could. The principal part of their attention should be directed to the amalgamation and subsequent processes.

Mr. T. K. Rose desired to say a word on a single point in which he was completely in accord with the Author, viz., as to the necessity of drying all ores before dry crushing. Mr. Western had given the results of some experiments as to the amount of water which certain hard lumps of quartz would take up, and he had expressed the opinion, which was contrary to the Author's, that most ores did not require to be subjected to any special drying before going through some such dry system of crushing as that in use with Krom rolls. There were no doubt many present who could speak on the subject from a much wider experience than himself, but he had not heard any dissent from Mr. Western's conclusions. His own experience was limited to the ores of Western America, and he must say that so far as those were concerned there was not one ore in ten that could be put through the rolls without previous careful drying. The amount of moisture that Mr. Western found in ores, running from 1 to 5 per cent., was certainly far below the average of the Colorado ores. The presence of quite a small percentage of clay was sufficient to clog the screens unless previous careful drying was resorted to, and that very small percentage was present in every Colorado ore that he had ever seen. A very small amount of moisture and clay would cause such a partial stoppage of the screen, that the capacity of the mill would be seriously reduced even if crushing could be done at all.

Mr. C. G. WARNFORD LOCK said he thought some confusion had arisen on the question of wet and dry pulverizing through the rather loose use of the words "wet" and "dry." As applied to ores, the terms "wet" and "dry" were simply relative. There were hardly any ores really dry at any time; but wet crushing was very distinct from dry crushing. It was quite possible to dry crush an ore which was not really absolutely dry. He did not think it

Mr. Lock. was Mr. Western's intention to claim that his rolls would deal with every ore, even after it had been for some time above ground, which materially helped in its desiccation. In the use of Krom rolls, too, of course, the aspirator causing a current of air tended to carry away a certain amount of moisture, and reduced the difficulty. Any proportion of clay, as clay, until it became dried, would have a detrimental effect. He did not quite understand from the Author's remarks why there were certain classes of gold quartz for the treatment of which rolls could not be recommended as more advantageous than stamps or mills—as for example, quartzes in which gold was extremely finely divided. It was not very obvious why they should not be usable for that purpose. Later in the Paper the Author stated, "Stamps as dry crushers are objectionable, because in practice it is found that their capacity for such work is considerably less than their capacity as wet crushers." As a matter of fact, the dry-stamp battery had been used in Australia for some time, and had given good efficiency at a very low cost by the introduction of an aspirator to carry away the fine as created, as in the case of Krom rolls. The Author also spoke of the "instantaneous powerful impact such as that given by a stamp," referring to the gravitation stamps. His own impression was that an "instantaneous powerful impact" would never be obtained in a stamp except when the mortar was nearly empty. They did get instantaneous powerful impact in the case of rolls, which was very clearly shown, he thought, by the difference in the character of the crushed ore in the two classes of machine. In crushed ore from rolls it would be found that the angles were very sharp indeed; the ore had been apparently broken in its natural lines of cleavage, whereas ore pulverized in a stamp battery would be found to be very much rounded. In his description of the pneumatic pulverizer the Author stated: "The makers claim that the high temperature of the currents employed, through which every minute particle of ore must pass, causes them to become very hot and dry, producing a beneficial effect upon sulphurets and ores containing so-called 'rusty gold.'" That was a very interesting statement, but he should almost doubt whether it was actually based on facts. According to all their experience, the temperature necessary to have much effect upon sulphurets or ore containing rusty gold would be something more than would be obtained in a crushing-mill in that way. The statement in the last paragraph but two of the Paper was contradictory to a previous statement. The Author there stated that "the ideal form of pulverizer is one which breaks the

quartz and liberates the gold from its matrix"; and later on he Mr. Lock. said that he had endeavoured to show in what respects gravitation stamps failed to accomplish that end. He alluded to the pounding action, whereas shortly before he had referred to the powerful impact which caused crushing without the grinding.

Mr. JAMES ARMER said he had lately had occasion to see some Mr. Armer. Ball mills made on the Continent which had worked exceedingly well. They were used largely on gold and silver ore in some parts of the world, but not so largely on the whole as other machinery; in fact, they were comparatively new. Still, the simplicity of the machine commended itself to any engineer. Coming somewhat nearer home, the use of them at the Royal Freiberg mines by Mr. Bilharz had been found exceedingly satisfactory. There, he supposed, was the only gold-mining machinery in use in the northern parts of the Continent. Ball mills were, he believed, used in Transylvania, but he had not much information on that subject. His own experiments had been confined to basic slag and cement clinker; but he thought he should say, in justice to Messrs. Gruson & Co., the well-known makers in Germany, that the output that he had seen in each case was very much in excess of that stated in their own publications. Of course he referred only to dry crushing. He knew nothing of the machines for wet crushing, although he saw no reason why they should not do perfectly well. The output of the machines in the case of the basic slag was 8 tons per day with a mill about 6 feet 6 inches diameter. The mill consisted of a number of shelves arranged in a cylindrical drum, and the drum contained a number of balls of hard metal. As it revolved, the balls fell from one shelf to another. The depth of the fall was not great, but there were a great number of balls, and the number of strokes in a given time was of course considerable. The sieves, which were situated in the extreme outside of the machine, were protected by perforated plates, which formed the shelves on which the balls fell. That protection struck him on several occasions as being exceedingly useful, and he believed that in practice it effected a great saving in sieves. The sieves were found to wear very rapidly in some machines, notably in the Huntington mill, whereas in the Ball mill he believed they wore a very much longer time. In the proceedings of the Society of German Engineers, at the beginning of this year, it was stated that the Huntington mill required new sieves in four days. That, of course, must have been a special case; but in no case did a Ball mill require sieves at a less period than several months. The

Mr. Armer mill also had another advantage, inasmuch as it might take large pieces about the size of a fist, and therefore in many cases would not need a crusher or breaker. The mills were up to 7 feet in diameter, and the wear and tear in a large size mill had been found in practice to cost from £6 to £14 10s. per annum, exclusive of the balls. He mentioned that case because the Author had said that the wear and tear of the plates of the mill would be very excessive. That might be the tendency, but the castings were made by a very special and hard mixture. The wear and tear, as would be seen, was very slight. The power required in the case in which he had ascertained definitely what had been done was from $2\frac{1}{2}$ to 3 tons per effective HP. per day.

Mr. James. Mr. CORDNER JAMES said that with many other speakers he had been exceedingly sorry that the Paper, though entitled "Gold-Quartz Reduction," did not deal with "reduction" in the larger sense—he referred to the treatment of gold ore from the time it left the mine to its delivery as bullion to the bankers. The Chairman had referred to Africa, and as he (Mr. James) happened to be recently connected with processes for the reduction of ore in Africa, he had had occasion to look about for a dry-crushing machine suitable to such a process, so that he had been greatly interested in the discussion on the Krom rolls. He had information in his possession to which no reference had been made, as to the fact that in Germany the Krom rolls were being used with water. The use of a pipe so as to allow a constant supply of water to be added to the ore as it passed through had considerably increased the efficiency of the machine as a crusher, pure and simple. With reference to the Husband stamps, he had once gone to Tregurtha Downs in Cornwall, where they had been working two heads, Husband's pneumatic stamps, for eighteen months, and he was informed by the management that during that period each stamp had crushed per diem 15 tons of hard tin capel. Those who knew what that meant would understand that the machine must be very effective. At the expiration of eighteen months, they measured the cylinders, and found that the wear was scarcely appreciable. With reference to the Elephant stamps, he had had direct command of a battery of such stamps in India. He did not think that many had been tried, but he found the lateral wear and tear on the top of the box by the levers which carried the heads was such as to require almost constant renewal. There was also the natural disadvantage of the heads being always in one position, and the wear was therefore inclined and very uneven. He found that the capacity of the Elephant stamps was much below that which the Author had

stated. With regard to centrifugal machines, the Huntington Mr. James. mill, with the roller action, had been referred to, and its efficiency was said to be principally due to centrifugal action. He regarded the Huntington mill as a favoured type of that description of machine. He happened once to have to take charge of a centrifugal pulverizer, and the first few days' work was very effective, and to their satisfaction. After a while, when the machine was not quite in the same order in which they received it, though it had been kept in working repair, they found that it ground $\frac{1}{2}$ cwt. of iron to every ton of ore that was crushed. It had been said during the discussion that the flouing of mercury was not produced in the way described by the Author. Whether it was exactly in that way, or not, he (Mr. James) knew that it was quite possible to flour mercury simply by mechanical action; therefore the flouing of mercury as described by the Author would certainly be the result of the cause to which he had referred. Professor Le Neve Foster had stated that they were able in a certain mine in Italy to treat ore containing 20 per cent. of pyrites by mechanical means, and obtain from it from 70 to 90 per cent. of the gold contained. To him it appeared to be a remarkable treatment. Professor Foster did not state how the power was obtained, whether by water or by steam—a point that would have considerable influence. In the reduction of gold quartz, the after treatment was simply based on commercial considerations. There was a point in the reduction and treatment when the gold recovered did not meet the cost, and there they stoppod. One speaker had stated that the sizing of the grains, &c., in gold quartz was not in his opinion of such importance as many other points. Taking that basis, and looking at the Witwatersrand, where they were stamping more than 100,000 tons per month, they would find that the average result of the treatment of quartz by the method indicated, simply passing it through the quartz mill, and then over the amalgamated copper plates, was 40 or 45 per cent. of the actual value. That would show the necessity for careful after-treatment, which depended a great deal on the separation of the grains, and for concentration it certainly required sizing. Mr. O'Driscoll, he believed, had mentioned that stamps were required for pulverizing, with a view to subsequent treatment. He did not know whether that was a correct view, or whether Mr. O'Driscoll meant that stamps were to be considered purely as pulverizers independently of the after-treatment. Unfortunately, the action of the stamp-mill and that of amalgamation were so closely connected that one could not be considered independently of the other. If the stamp-

Mr. James. mill was to be regarded purely as a pulverizer, the idea of its efficiency might be considered quite distinctly from that of its capacity when also an amalgamator. The efficiency of a stamp-mill might be considerably increased by having additional discharges to those generally used when amalgamation was adopted. By the ordinary system of amalgamation, with one discharge, there was about as much pulp as the tables of any ordinary size could take. If, on the contrary, effective means of amalgamation were employed, after the stamps had delivered the maximum quantity, then by means of additional openings for the discharge of the product, the ordinary yield of the stamp-mill might be increased by at least 40 per cent. It had also been remarked that in the revolution of the stamp the action ceased immediately it came in contact with the material to be pulverized. Unfortunately, his experience did not quite tally with that. He had seen mills working ninety drops per minute in which the interval of time between the down blow and its rising again was practically imperceptible, so that the revolution seemed to be absolutely continuous. There was a grinding action produced by the rapid revolution of the stamp, and as a consequence grinding and sliming must be produced in a stamp-mill. In that respect the Huntington mill seemed to have a considerable advantage.

Mr. Vaughan. Mr. WYNDHAM VAUGHAN said that the Author in the series of Tables exhibited, dealing with the milling or reducing capacity of the different classes of machines described in his Paper, had omitted to state what was the ore used when such results were obtained. When a comparison was made between the various machines, it was most important to know under what conditions, especially as to material and fineness of reducing, such tests were made. It would have been a most useful addition to the information already supplied by the Author, if some further data had been given as to the milling and reducing capacity of each class of machine, when tested under precisely similar conditions, and, more especially, when using various descriptions of gold-bearing ores.

Mr. Ogle. Mr. P. J. OGLE said that the Author had come to the conclusion that there were only three forms of pulverizer capable of general application, namely the gravitation-stamps, Huntington mills, and Krom rolls; but he qualified this opinion as to the two latter by saying that the Huntington mill was only applicable to soft ores, while the Krom rolls could only be used with dry ores. That left only the gravitation stamp in the field. He (Mr. Ogle) thought they could not stop there. If some gentlemen who had had experience

with some of the other machines would give them the benefit Mr. Ogle. Of it, they could see in which direction to look for future improvements, though he agreed with a previous speaker that they should look rather to the development of existing machinery than to any novel form of pulverizer. The Author had given examples of four stone-breakers. The first was the well-known Blake, which everybody continued to use on account of its simplicity. That was improved upon by the lever-motion machines of Mr. Baxter and Mr. Marsden. The efficiency of stone-breakers depended on the wear and tear of iron per ton crushed, and also on the output per HP. He thought that the improvements in the lever breakers were considerable, and that the power required per ton of ore with them was less. He thought, too, that there was something to be said in favour of a uniform size when the ore had to be delivered to another machine. In the jaw-breaker, as at present designed, it was too much to expect to bring a rock 10 inches in diameter down beyond, say, 2 inches. In his opinion the most economical result could be obtained from a stone-breaker of the rocking-jaw type when working within this range. Before passing on to the question of stamps, he thought they ought to consider the advisability of introducing an intermediate crusher, not a stone-breaker designed for large rock, but one specially designed to take in rock 2 inches in diameter, and to reduce it, say, to $\frac{3}{4}$ inch diameter. He had had some experience with fine crushers, and he thought that a fair efficiency could be obtained from a rocking-jaw crushing down to $\frac{3}{4}$ inch, but not beyond that. There was an objection to Marsden's fine crusher. It had not only a rocking jaw, but a jaw with an upward and downward motion that produced considerable grinding action on the teeth. As most of the crushing was done by the points of the teeth, as soon as these began to wear, the efficiency of the machine rapidly fell. Before coming to the final pulverizing, the first thing to be considered was the size to which the ultimate product was required to be brought. The average mesh for stamps was about 40, and the question was whether that 40 mesh was the size which was really wanted, or whether that degree of fineness was generally adopted because it was found that it was not economical to pulverize finer in a stamp battery. He believed the latter was really the case. It had been stated that in the Witwatersrand, for example, there was only about 45 per cent. of the original gold recovered in the first instance. Was not that because the ore was not stamped fine enough? He thought that was the case. He therefore thought that finer crushing was desirable if it could be done

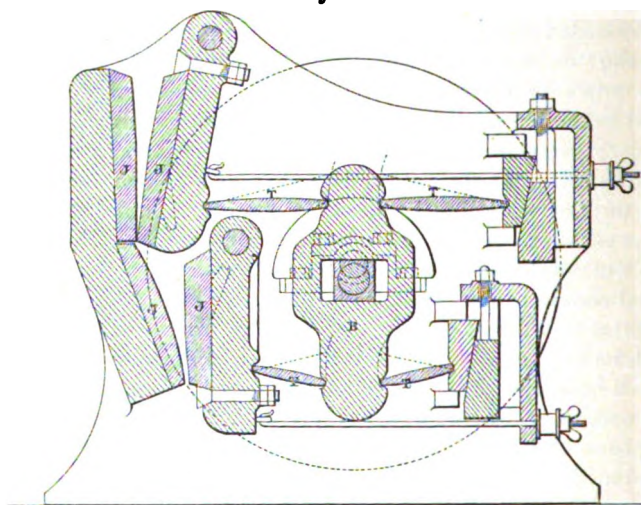
Mr. Ogle. economically and rapidly. With a view of arriving at a very fine crusher—he did not say 120, but something finer than at present—ought they not to have even another intermediate crusher? He thought that the ore might be most economically reduced from $\frac{3}{8}$ inch to 10 or 20 mesh by rolls. He had had experience with high-speed rolls for this size, and had found them very economical for reducing to 20 or 30 mesh, because it was not necessary for the rolls to wear so evenly; if there was a slight unevenness, it did not affect the result. Having arrived at 20 or 30 mesh, the question of the final machine had to be considered, and then it had to be decided what form of crushing it was right to adopt. Should it be crushing by impact, like stamps, or rolls, which was somewhat the same thing—it was a case of two bodies rapidly brought together and crushing by impact, as in the case of the Huntington mill—or should it be grinding, or should it be a combination of the two? Grinding, of course, gave the most even sample; but the wear and tear was so tremendous that it ceased to be economical. A machine combining the two forms of crushing was therefore the most desirable. The only form of machine that really met the case, in his opinion, was a ball crusher of some sort. The ore was not only crushed by the balls rolling on the ore and crushed by impact, but a grinding action was also produced by the balls rolling round themselves, as it were. There was, however, a difficulty in amalgamating the gold in a machine of this type. If a high-speed machine was used, the mercury was so washed about and churned that amalgamation was almost impossible. He therefore suggested that a low-speed was much better than a high-speed machine. This difficulty of amalgamating would apply to all centrifugal machines, which he thought were a mistake in mining-machinery. First of all, the wear and tear was much greater; secondly, the amount of oil required was much greater, and, as a rule, the machines were not such as would stand steady and continuous work without a great deal of attention. He thought he should not be going too far in saying that there should be four machines for crushing: first, the stone-breaker; secondly, an intermediate or fine stone-breaker; thirdly, rolls; and finally, a ball crusher. Those were all machines which in some form or other were at present in work, and it might be expected to get a better result with regard to the amount crushed per lb. of iron used, and per HP. absorbed in driving the machinery, if the work was divided amongst these four machines.

Mr. WORBY BRAUMONT said that during the past fifteen years a great many machines had been made, and most of them he might

say to replace the very simple stamp. In putting most of these **Mr. Beaumont.** machines forward the arguments had been based upon the same sort of reasoning by which a man might argue that the sledge-hammer which he wished to sell was the best all-round hammer, although often only required to drive tin tacks. What he meant by this was that there was no one machine that would in all cases answer for all the various purposes to which mining-engineers had to apply them. These stamps, very simple machines, were very much like the sledge-hammer or the flogging hammer; they would do for a great many purposes. They were exceedingly simple, and any one could see what was wanted to make them do work under almost any circumstances. But most of the other machines that had been brought forward with the object of reducing material for the purposes of the gold miners had proceeded too much on what among milling-engineers is called the "sudden death" principle. They mostly proceeded to do too much in one operation. It had been already said that gradual reduction should be the guide of those who had to set up machinery. In a very large number of instances it was quite impossible to select, or at any rate to buy that class of machinery which would do the work in the most economical if not in the most efficient manner. What he wished to emphasise was this: that to do the work well, whether on the hardest or on the softest ores, the material should as far as possible be separated into stages. Where the capital would not permit, or when the work was only experimental, he at once admitted that was out of the question, and they must fall back on the simple stone-breaker and stamps. Otherwise it was necessary to consider what had to be done in order to reduce large pieces of rock down to the small sizes necessary to release the gold. Too much work was done in over-treatment of the fine material produced by what he might call the first cracking. Very much, as in corn-grinding, there was this necessity for the separation of the stages. Taking, for example, the edge-runners as being the simplest to convey an illustration of what had to be done in breaking up a piece of rock with the least expenditure of power; the small material made by the first cracking helped to support that which still remained to be cracked, and over and over again the edge-runner would go over that which was being supported by the material which was already fine enough. The fine material produced a bed which effectually protected from crushing a large quantity of that which should be crushed. Separation as rapidly as possible was therefore necessary, and the crushing should be done in as many

Mr. Beaumont. stages as possible, not only in order that grinding and rubbing of the products should be avoided, but in order that the product desired should be obtained as cheaply as possible. As far as power with reference to work was concerned, the stone-breaker was amongst the most economical machines. Too much, however, was often expected from one machine. No machine could receive large masses of rock and give a uniform small product. The result was that as many machines as could be bought could be economically bought also if there was work to do, and each one should have as small an amount of reduction as was possible to perform, if it was to be done economically. As an illustration of this, he referred to the Coles stone-breaker (*Fig. 23*), a machine

Fig. 23.



THE COLES STONE-BREAKER.

designed so that each set of jaws should have a very small amount of breaking or reduction to perform. It had two pairs of jaws, J, each pair receiving its motion from one vertical moving piece, B, as in ordinary machines, but the lower pair was so arranged as to make two strokes while the upper pair made only one. This was done by arranging toggles, T, of different lengths, so that one pair, the lower, moved on both sides of a line normal to the line of motion of B. Therefore, assuming that the piece of rock that entered the upper jaws was broken in two—it would in most cases be broken into more—then the lower jaw was supposed to be able to take the product from the upper jaw, and,

with its short length and double frequency of stroke, to break that material and effectively give a uniform, or a more uniform, smaller product. Such a machine was proposed as being capable of performing, not twice the work of any ordinary stone-breaker, but something approaching that, and it was suggested as a means of obtaining gradual reduction and enabling the machines that followed to receive material much more likely to meet their capacity. The Huntington mill had been deservedly mentioned as one of the most efficient. One of the reasons for the efficiency of that machine was that while it would deal at a somewhat diminished rate with large material, by the nature of its action a sorting went on which enabled the rollers to act on material more uniform in size, and so to give a more uniform output. It did not crush the fine material over and over again. He would ask the Author to give them a few more figures with regard to the power used in many of the machines referred to. He had been asked on various occasions to witness the working of different machines, and whenever he had asked for a statement of the power actually consumed by them, or to be permitted to ascertain actually the power used, something had invariably happened so that the experiment could not be carried out on the day proposed for his visit.

Mr. THOMAS CORNISH would have liked to have heard the Author mention the Sutherland mill. It was one of the best, outside the ordinary stamp-mill, he had seen; but owing to the owner and inventor not having the means to bring it forward, it failed to meet with the support it merited. In the Colony of Victoria the subject of gold-quartz reduction had received considerable attention. The quantity of auriferous quartz raised was over 25,000,000 tons, valued at £50,000,000. The machinery in use consisted of nine hundred and fifteen engines with a nominal HP. of 20,852, five thousand nine hundred and one stamp-heads, twelve stone-breakers, and seventy-eight pulverizers not driven by steam-power. The weights of the stamp-heads with shank and lifter varied from 5 to 9 cwt., the fall from 6 to 12 inches, the number of strokes per minute from fifty to eighty-five, and the number of holes per square inch in the gratings from one hundred to two hundred and fifty. The cost per ton for pulverizing varied from 5s. to 20s. As an example of economical milling, he might instance the North Cornish mine at Daylesford, where £1 profit could be made per ton on 8 dwt. ore.

Mr. W. SHELFORD said, that having had some experience in mining of various kinds, although he had not closely pursued it of late years, and having been, some twenty or twenty-five years

Mr. Shelford, since, responsible for the working of gold mines in Nova Scotia and Colorado, he had felt the greatest interest in the Paper and the discussion which followed it. It had given him an opportunity of comparing the appliances of the present day with those in use at the time he spoke of. The comparison showed that twenty-five years ago the Blake crusher was a new thing, which was rapidly coming into use; the stamps were an old thing, and they were used in the absence of anything better. At the present time the Blake crusher seemed to be accepted by everybody as a good thing, and the stamps were certainly not yet superseded. He entirely concurred in the first paragraph of the "General conclusions" arrived at by the Author. The consideration of the working facilities at the proposed mill site was necessary beyond doubt, even where the gold occurred as free gold in the ore; it was still more necessary where, as in some cases, it was disseminated invisibly throughout the mass, and where, as in many cases, it was enclosed in pyrites, and became a refractory ore. His own experience in working free gold was that it was most difficult to get the gold into the pockets of the rightful owners; and with regard to refractory ores, however rich they might be, it was absolutely necessary that the country should be sufficiently developed to contain such works for their proper reduction as would alone make the mining of such ores a success. As a Member of the Council, he desired to say that it was interesting to himself, as it must be to other Members of Council sitting there week after week, to see that the audiences varied according to the Papers. When they had mining papers they had a mining audience; when they had railway papers they had a railway audience; for electric papers an electric audience, and so on. This was due to the fact, which could not be too often repeated, that the Institution was the parent Institution of the profession, and that it contained within its body numerous practitioners in all classes of engineering.

Mr. Curtis. Mr. A. H. CURTIS, in reply, said that he was glad to find that in the main his expressions of opinion were approved, and that there was no great difference between them even on points of detail.

With Mr. Western, he favoured "gradual reduction" where the cost of such working was not prohibitive. There were, however, ores containing very finely-divided gold in a very hard matrix; and, for many of those, he should prefer to use stamps, because of the excessively fine pulverizing which such ores required. That fine pulverizing could not always be obtained by one or even two

returns of the crushed ore to the rolls. He had given 25 HP. as Mr. Curtis. the driving requirement for a single Krom-roll plant capable of crushing 2 tons of ore per hour. Mr. Western, supplying a supposed omission, had stated the requirement as 32 indicated HP. Now, as the effective HP. of an engine was from one-fifth to one-sixth less than the indicated, it would be seen that he stated the required driving power correctly. He also called attention to the fact that the text of his Paper gave the actual, and not the nominal, HP. required for gravitation stamps. He agreed with Mr. Western that the manufacturer's expression "nominal HP." was an unsatisfactory one, although, when it was used of stationary engines, it was understood that from two and a half to three times that power could be effectively obtained at the shaft or fly-wheel. In the case of the Huntington mill, he had stated the nominal HP. required so as to correspond with the term used by the makers. If desired, he should be happy to frame a Table showing the indicated HP. required per ton of quartz treated by the principal fine pulverizers. He might say in passing that, if the term "nominal HP." was so useless as Mr. Western stated, it was surprising to him why so many mining-machinery makers, including Mr. Western himself, retained it even at the present time in their catalogues. Mr. Western made no reference to the work of his rolls on argillaceous ores; and, while quite agreeing with him that the majority of gold-quartzes were very free from argillaceous matter, and that, in general, they came to the mill in, at worst, a slightly moist condition, he must say, from his own experiences, that argillaceous and wet ores were not rare things, and further, that, in estimating moisture where dry crushing was to be effected, percentage by bulk was a far more important consideration than percentage by weight.

In regard to the points raised by Mr. O'Driscoll, reference to the text of the Paper would show that he had clearly indicated what the aim of mill-designers and mill-managers should be in view of the extraction of gold from ore after it had been pulverized. His observations were based principally on what he had seen in South Africa, while he had had opportunities of acquiring information in America and in India. Mr. O'Driscoll was, he believed, more familiar with Australian practice. Mr. Curtis had, however, to thank him for pointing out an error in the Paper, as he was aware that it was unnecessary to roast concentrates before treating them by the cyanide process.

In reply to Professor Le Neve Foster he might say that the percentage of sulphurets which had come under his notice in free

Mr. Curtis. milling had generally varied from 1 up to about 5. He regarded quartzes containing from 5 to 10 per cent. of sulphurets as highly mineralized; and, speaking generally, he should consider the presence of more than 10 per cent. of sulphurets as rendering battery amalgamation unadvisable. He was aware that the decomposition of cubical iron pyrites—the ordinary yellow pyrites—was not generally a rapid process; but the term “pyrites” in gold mining included other sulphides of iron, notably arsenical pyrites and sulphides of copper, which were more speedily decomposed in the battery. He should be interested to know the precise nature of the pyrites contained in the ore of the gold mine in the Valente-goria referred to by Professor Foster. The ore was stated to contain 50 per cent. of pyrites, and 80 per cent. of its gold value was said to be saved by the amalgamation process. He ventured to suggest that the sulphurets in that exceptional ore were probably ordinary cubical iron pyrites, which was not decomposed so rapidly as other sulphides of iron which occurred in gold-quartzes; and he ventured further to suggest that the gold contained in the ore was of a coarse nature, and possibly occurred in the siliceous and not the pyritous portion of the ore. Did the ore contain any arsenical pyrites? The complication of the Gates crusher was somewhat exaggerated by a perspective section such as that exhibited; and the users of the machine—who were, after all, its best critics—made, in general, no complaint on that head. In speaking well of gyratory breakers he must not be understood to disparage jaw-crushers, which, indeed, had too good a record to need defending. Professor Le Neve Foster scarcely did him justice in stating that his objection to Cornish rolls, with lever-and-weight compression, was that they were primitive machines. If he had read on, he would have found that the objection to them as gold-quartz crushers was their small capacity and little durability as compared with rock-breakers. Again, that gentleman, without intending to misrepresent him, had stated that Mr. Curtis had said: “In gold-quartz dry-crushing operations, the very fine dust is unlikely to carry with it any estimable quantity of gold.” That was an incomplete quotation. If he would read the whole paragraph he would see that the Paper was referring to the separation of the fine quartz-dust from the more valuable product of the rolls by means of an exhausting-fan, driven at a speed so carefully regulated as to render the carrying of particles of gold along with it unlikely. He had had ample opportunity of examining quartz-dust separated in this manner. Besides, having

himself pulverized gold-quartzes to pass through sieves of the finest Mr. Curtis. mesh used in assaying gold ores (6,400 holes to the square inch), he would be the last person to hold the opinion attributed to him by Professor Foster. In the matter of the origin of gravitation-stamps he accepted, with interest and humility, the historic lore contributed in the discussion, but was more concerned with their merits and defects. The objection to Husband's stamps, on account of the necessity for the use of oil for bearings, was equally applicable to gravitation-stamps; but, with reasonable precautions, there need be little trouble on that account. As he had recommended pneumatic and steam-stamps principally for coarse and medium pulverizing, he did not regard the speed of 140 blows per minute, noted in the Appendix, as a serious objection to the use of Husband's mill.

Objection had been taken by Mr. S. H. Cox to the statement that as much as 75 per cent. of the gold contained in ore treated in the Huntington mill was generally saved in the pan, and the conclusion hazarded that the Author's experience must have been only with ores containing very coarse gold. The following statistics, which were absolutely trustworthy, might be of interest to Mr. Cox. At the American Eagle mine, Butte County, California, the Huntington mill required for the proper treatment of the ore a No. 7 slot-punched screen (corresponding to 30-mesh, or 900 holes per square inch), and 50 per cent. of the gold was saved inside the pan. At the Edman mine, Plumas County, in the same State, a No. 8 screen (corresponding to 35 mesh, or 1,225 holes per square inch) was used, and 80 per cent. of the gold was saved in the pan when the gold was coarse, and 50 per cent. when the gold was fine. At the Gambetta mine, Fresno County, a No. 9 screen (corresponding to 40 mesh, or 1,600 holes per square inch) was used, and 90 per cent. of the gold was saved in the pan. The fineness of the screen used was a criterion of the fineness of the gold contained in the ore under treatment. He might say, in reply to one gentleman who had criticised the consistency of his opinions, that a more careful reading of the text should be sufficient to show that in differentiating between the various fine pulverizers, he had not in any way contradicted any opinion expressed in an earlier paragraph.

He was much indebted to Professor Roberts-Austen for his valuable contribution to the discussion, and he fully recognised the importance of the metallurgical side of the question. The materials used in the construction of crushing and pulverizing appliances constitute a consideration of extreme interest and im-

Mr. Curtis. portance, "wear and tear" being at present, in most cases, a very serious item. He trusted that the subject of durability of materials, as also concentration and chemical processes of gold extraction, would receive the full attention which they deserve at the hands of some member or members during next Session. The processes which he had described were almost wholly mechanical, and he had accordingly used the word "reduction" in a mechanical rather than a chemical sense. The original title of his Paper was: "Gold-Quartz Reduction: the Principal Crushing and Pulverizing Machines and Processes," and he regretted it had been necessary to abridge this explicit title. The opening paragraph of the Paper, however, sufficiently indicated its scope.

In reply to Mr. Woodhouse, he had to say that in limiting his recommendation of dry crushing to cases in which subsequent operations were conducted by dry methods, he was referring to the dry-crushing of ores which had been previously desiccated by mechanical dryers. The cost of such drying was, in most mining districts, a large item; indeed, in many cases, the cost of fuel was so great as to render the drying of ores by heat an impossible undertaking. To dry an ore before pulverizing it, and then, after pulverizing, to saturate it with water appeared to him to be an uneconomical process, except in special circumstances. Cost of working was the most important feature of mining operations, and the success of a mine depended, not simply on the theoretical merits of the working methods adopted, but on the relation between the cost-sheet and the value of the ore.

In compiling his Table of Capacities, &c., of Fine-Pulverizing Machines he had taken, as the material under treatment, gold-quartz of average hardness (a term well understood by mining engineers), and had in all cases considered this material to be pulverized to "medium fineness," which, in gold-quartz operations, was about from 30 to 35-mesh (900 to 1,225 holes per square inch). This would answer Mr. Wyndham Vaughan's query.

Mr. Giles. Mr. ALFRED GILES, M.P., Vice-President, said he was sure he should not appeal to the members in vain in asking them to give Mr. Curtis a cordial vote of thanks for his excellent Paper. Having heard his description of the various machines employed for gold-quartz reduction, and having noticed the industry which he had displayed in preparing drawings and collecting information, members could have but one opinion as to the value of the Paper. Mining was a subject in which many of them were interested; and some, he feared, had burned their fingers in dealing with it. When it was considered that ten pennyweights of gold per ton was

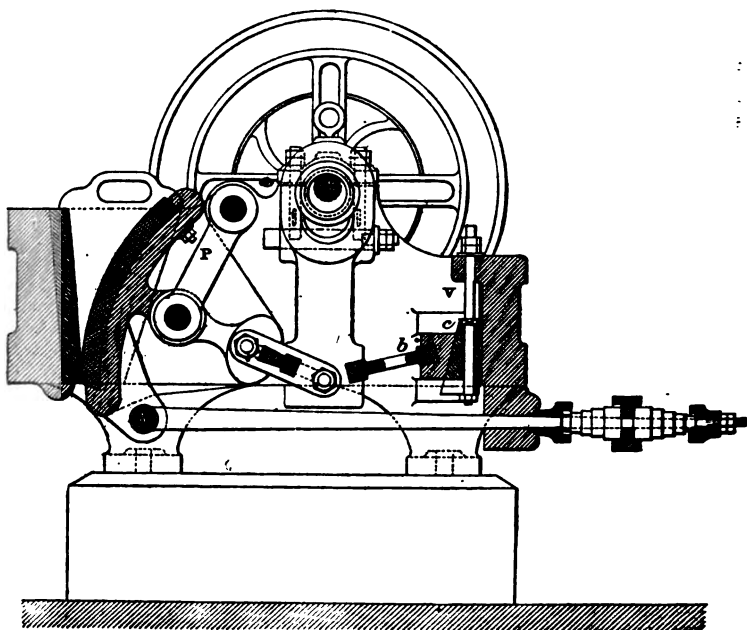
sufficient to pay when the material was properly worked, they Mr. Giles. could see how imperative it was that the machines for reducing the ore should be of the most perfect description. It was remarkable to observe that the discussion had been maintained in many cases by young members; that perhaps proved that mining, though as old as the hills, was still endowed with vitality. For looking at what had taken place at Fort Salisbury, where pre-historic buildings had been discovered which were assumed to be connected with the gold-mining industry of the days of King Solomon, they ought to be able to continue that industry, and to make it pay. There was good reason to doubt whether the means adopted for extracting gold in those days were anything like as perfect as those of the present day. In view of the large income derived from gold-mining, a great many considerations would be suggested by the Paper, which would be well worth attention in the future.

Correspondence.

Mr. G. ATTWOOD was much struck with the care and general Mr. Attwood. accuracy of the Author's statements. The subject was a difficult one to handle on account of the numerous inventions which had been made during the last thirty years for the purpose of improving gold-quartz reduction; nearly all the inventions having some good points but failing in the main. The result of practice had reduced the machines most extensively employed to gravitation and steam-stamps, the Krom or similar rolls, and the Blake jaw-crusher. With regard to the Author's statement that effective work was done only at the instant that the stamp descended on the ore, it was possible that such was the case in the early days when the stamp was made in square or angular forms; but when the revolving stamps were brought into use, a rotary motion was given to the stamp as well as the blow, which contributed a grinding motion as well as a pounding one. This action could easily be seen by watching a battery at work with the screens removed. In reply to an objection to stamps brought forward by the Author, he pointed out that modern gravitation-stamps were so arranged that, with ordinary care, no oil or grease should contaminate the ore either in the battery or in the feeding-hopper. For the last twenty-five years he had been looking for a wet-crushing machine that would supersede the gravitation-stamp, and he was still unable to recommend any other appliance. Even for

Mr. Attwood. dry crushing he had found the stamp equal to jaw-breakers and rolls. Indeed at the great Comstock lode in Nevada, where he was engaged for nine years, at a time when no expense was spared in trying every new form of machinery, the gravitation-stamp was selected in spite of its many defects. The steam-stamp had been brought to great perfection in the Lake Superior copper district, and he had recently seen at the Calumet and Hecla mines a mill of fifteen stamps pounding 2,500 tons per day of conglomerate.

Fig. 24.



THE SCHRANZ STONE-BREAKER.

containing native copper; the screens in that case being made of steel plates with circular punched holes about $\frac{1}{10}$ inch diameter.

Mr. Bellom. Mr. MAURICE BELLOM (Paris) wished to compare the stone-breakers described by the Author with a machine, known as the Schranz stone-breaker, he had recently seen at work in Germany. In this machine the ore was subjected to a simultaneous crushing and grinding motion. The accompanying drawing (Fig. 24) indicated the construction of the machine so clearly that it was merely necessary to add a few details. The two jaws were made

of cast-steel, and the space between them might be regulated at will by means of a vertical screw V, which adjusted the wedge C. The short connecting rod B of cast-iron, had been designed with such section that it would be broken before any other part of the stone-breaker, if some very hard material should find its way between the jaws. Details of the different sizes in which this machine was made would be seen from the Table given below. The advantages of this machine consisted in the fineness to which the ore could be brought (8 millimetres), and in the fact that there was no necessity to employ the trommels usually adopted with American stone-breakers. By reason of the acute angle at which the jaws were placed, the Schranz stone-breaker performed the function of the trommel, the jaws being able to seize and crush the pieces of ore, the size of which prevented them from engaging between the surfaces of the cylinders, whose angle could not be reduced below a certain limit without giving to the diameter of these cylinders an exaggerated size. With his contribution to the discussion, Mr. Bellom sent a lengthy statement of the mathematical principles on which the construction of this machine was based.

	I.	II.	III.	IV.	V.
Useful surface of the jaws millimetres	{ 200 × 150 }	{ 300 × 200 }	{ 400 × 250 }	{ 500 × 300 }	{ 600 × 350 }
Number of revolutions per minute of the driving pulley	250	250	250	250	250
Diameter of the driving pulley millimetres	400	500	650	700	1,000
Width of the driving pulley millimetres	100	125	150	160	180
Space occupied } Length "	1,050	1,450	1,650	1,800	1,950
by the } Breadth "	900	1,150	1,400	1,700	2,000
stone-breaker. } Height "	900	1,150	1,350	1,550	1,650
Weight of the machine kilograms	800	2,500	4,500	6,500	9,000
Weight of one pair of jaws kilograms	100	200	300	400	500
HP.	1-2	3-4	5-6	8-10	10-12
Quantity of ore crushed kilograms per hour	{ 600- 1,000 }	{ 1,500- 2,000 }	{ 2,000- 3,000 }	{ 3,000- 4,000 }	{ 4,000- 5,000 }

Mr. R. BOLTON observed that the Author gave descriptions of rock-breaking mechanisms in which the breaker-jaw was hinged above and in which it was hinged below, to the advantage of the latter. There was, however, a further form, employed in the Lancaster stone-breaker, made by Messrs. Penny & Company, of Lincoln. It was largely used in the United States, its peculiarity

Mr. Bolton, being that the jaw was hung on a toggle, or vibrating link, above and attached to the reciprocating arm below, whereby a compound motion was attained with very beneficial results as to output and regularity of size. The machine further possessed a simple mechanical arrangement of driving-gear by a double cam on the driving shaft, upon which was a broad iron roller fixed to the reciprocating-arm. This had the effect, as compared with eccentrics or cranks, of doubling the number of reciprocations at a given speed and of reducing the friction of driving. By a simple mechanism of one lever resting upon another, a control over the stroke of the jaw was attained during operation, and the size of the product might be varied in size at will. This machine seemed to possess advantages demanding attention. One of Sholl's pneumatic stamps was worked for some years near St. Austell, and very fine crushing was done with it. The death of the inventor had since then prevented the extension of his system; but there was a good deal to be said in favour of the use of a cushion of air in high-speed stamping. The Huntington mill, with the improvements in detail introduced into it by Mr. Paxman, certainly formed, in Mr. Bolton's opinion, the best fine-crusher in the market.

Mr. Chenhall. Mr. J. W. CHENHALL observed that, notwithstanding the long indictment of defects adherent to the stamp-mill brought forward by the Author, it still held its own as the most effective machine, and the one most cheaply manufactured and manipulated, in the market. This arose from the fact that the mill-man could always rely—when he had a well-constructed stamp-mill—on the quantities he could pulverize, and on the results he could obtain. As a pulverizing-machine no other contrivance could compete with it in effectiveness. Steam-stamps have been very successful in their application to the crushing of copper ores on Lake Superior, where it was not necessary to carry the stamping to so great a degree of fineness as in the case of gold-quartz reduction. The Husband quick-speed stamps had also been successful to some extent in the stamping of tin-stone in Cornwall. The stamp-mill, however, could not be considered well adapted for dry stamping, the continued concussion of the stamps making it impossible to collect the dust from the battery-box. This accumulation of dust was very injurious to the workmen employed in the mill. He had had experience in the crushing for dressing of large quantities of copper ore by means of modified Krom rolls, used as wet crushing machines. In this case it was unnecessary to crush very fine, and, consequently, large quantities could be crushed, the output per day amounting to 1,000 tons with six sets of rolls, each set

containing three pairs of rolls. The work was very satisfactory; Mr. Chenhall. but any attempt to increase the fineness influenced the output very largely, and the grooving of the surface of the rolls could never be entirely prevented. All the rolls and roll-shafts were consequently made in duplicate, and the rollers were removed immediately they showed signs of wear from the last mill to the higher set of rolls, where the crushing was less fine. The cause of the failure of the various forms of ball pulverizer was, probably, that gold-quartz, as a rule, was very hard, and the broken pieces had angular edges. Such materials when brought into contact with rubbing surfaces—as was the case in almost all ball pulverizers—which work at a high speed, the path of the machine and the balls were ground instead of the ore. While many of these machines might have a useful field of operation in the pulverizing of soft material, or as purely prospecting machines, they would never come into considerable use in the reduction of gold-quartz. The Huntington mill, which has many features to recommend it, could not be regarded as a machine to supersede stamps, particularly where very large quantities of ore had to be dealt with daily. Although interesting experiments had been made, no satisfactory results had yet been accomplished on a large scale with concentration and extraction of gold from quartz by dry methods.

Mr. J. H. COLLINS stated that the Author's general conclusions Mr. Collins. as to gold-quartz reduction might have been more briefly and definitely summarised in the following words: In the great majority of cases, stamps are the most advantageous; but where the ore is soft and brittle, and the gold is free and coarse, Huntington mills are sometimes preferable, whilst where dry-crushing is necessary Krom rolls are better. This, at any rate, had been the conclusion of men of large practical experience hitherto, and it was not likely to be altered for some time to come. But, in the Paper, it seemed to have been tacitly admitted as a disadvantageous circumstance in the use of stamps, that a larger proportion of slime was produced than was the case with other appliances for gold-quartz reduction. Though this was the fact, the conclusion that it is disadvantageous was too general. The production of much slime in gold-ore treatment was sometimes a positive advantage. Slime was merely very finely divided ore, and if the particles of gold in the ore were very fine and very evenly distributed, and if mechanical concentration and subsequent metallurgical treatment were for any reason out of the question, and these were very common conditions indeed, these very fine gold particles must be

Mr. Collins. saved by some form of amalgamation. It was obvious that the gold could not be satisfactorily liberated from the vein-stone except by bringing the ore into that extremely fine state of division termed slime. He had microscopically examined tin ores, in which the particles of tin oxide were less than $\frac{1}{500}$ of an inch long, $\frac{1}{1,000}$ of an inch wide, and $\frac{1}{2,500}$ of an inch thick. In gold ores the metallic particles were often far finer than this. It was evident, therefore, that unless such ores were reduced to an almost impalpable powder, the minute particles of gold could not be seized and retained by the amalgamated plates. This fine state of division must be obtained either by stamping through a very fine screen, or by subsequent grinding in a mill capable of doing finer work than could be done by a Huntington mill or by Krom rolls.

Mr. Commans. Mr. R. E. COMMANS remarked that there was one form of stone-breaker, the "Schranz" crusher (*Fig. 24*), which was not referred to by the Author. It was of interest, as it formed a link between the ordinary stone-breaker with reciprocating jaws, and the crushing rolls. The outward appearance of this crusher was not unlike an ordinary stone-breaker, but the action was quite different and resembled more that of crushing rolls. The movable jaw, instead of having a reciprocating motion, had a rocking one somewhat similar to the motion of a circular blotting-pad. A number of these crushers were at work, taking the place of rolls, and giving every satisfaction. One advantage this machine had, in common with the "Dodge" fine crusher, was that the opening at the bottom was constant, thereby securing a uniform-sized product. A point of some importance, where stone-breakers had to be sent abroad and long distances up country, was to keep down the weight of the various parts as much as possible, without at the same time reducing the strength of the machine. This object had been attained (by building up the machines, either with solid steel frames, or by the employment of strong tie-bolts to take up the thrust), with the best results, and the weight of the machine reduced about 50 per cent. How far crushing-rolls were suitable for very fine pulverizing had yet to be proved. Even the best designs of these machines had many weak points. It was, for example, almost impossible to keep the shells from wearing hollow in the centre, even when one of the rolls was given a slight longitudinal motion. The number of wearing parts was considerable, and when crushing dry, whatever precautions were taken, it was very difficult to keep a certain amount of the sharp grit from getting into the bearings. The shells and other parts of the rolls were further very costly to replace, and it was a

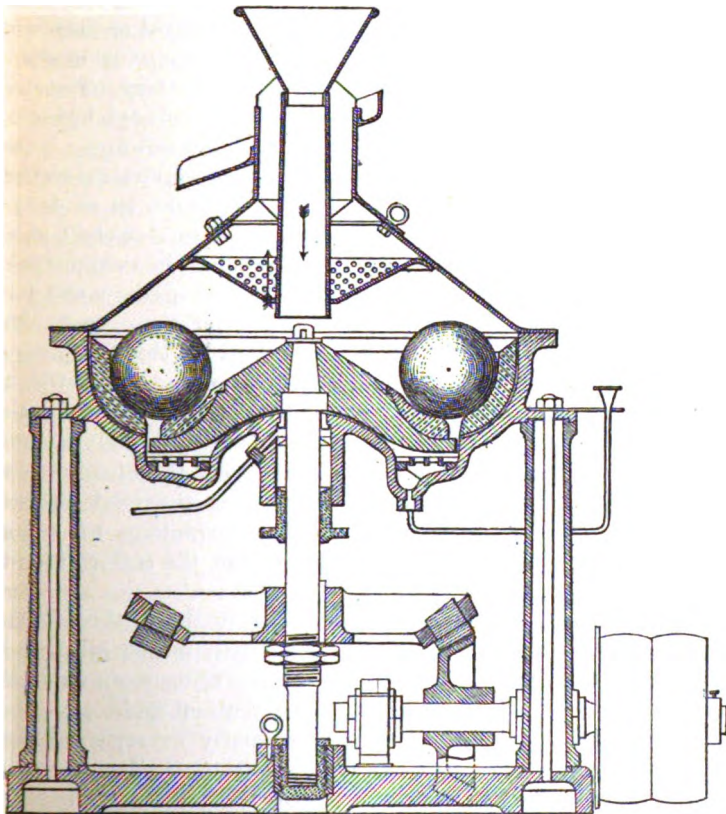
question whether, especially for dry crushing, equally good results, Mr. Commans. with considerably less wear and tear, could not be obtained by the employment of one or other of the numerous forms of ball-crushers in which the ore is crushed down by heavy balls revolving in a drum of more or less cylindrical form, the fine-crushed product passing out through sieves as soon as sufficiently reduced. The material crushed by rolls was broken down in a granular form, without the production of so much fine powder as would be the case if stamps were employed and, therefore, for ore-concentration and chlorination purposes, where extreme fineness was not required, the employment of rolls was no doubt advantageous. Without doubt, in order to crush properly with rolls, at least two pairs should always be employed, so as to gradually reduce the material, and a very good plan was to have a set of spare rolls, so that as soon as the lower pair of finishing rolls showed signs of wearing hollow these could be inserted in their place, and the pair of finishing rolls used some time longer as roughing rolls before being re-faced. A plan sometimes adopted for turning heavy rolls was to have a slide-rest fixed to the frame of the rolls, which permitted of the tires being turned up in position, and saved the rolls having to be lifted in and out. Although the Chilian mills had given exceedingly good results, the employment of ordinary edge-runners was hardly likely to extend for quartz-crushing abroad; because, not only was the output with these mills small, but also because the weight and size of the runners rendered their transport up country very difficult. Another objection was that, however narrow the face of the runners might be, it was impossible to prevent the grinding action, due to the slip of the runner on the path. This reduced the material to a fine impalpable powder, rather than to a fine granular condition. This grinding action, as well as the heavy weight of the runners, had been overcome in the Schranz fine-crusher, which was employed at Lauremburg, on the Lahn, in conjunction with the coarse-crusher above described, for reducing the mixed products from the fine jigs. This mill consisted of a revolving pan and three conical rollers. The rolls revolved on spindles fixed radially at an angle to each other of 120° . The inner ends of the spindles were rigidly fixed. The outer ends moved in a frame, and were capable of being pressed down by means of set-screws and rubber buffers on to the revolving pan, or annular crushing ring. As the pan revolved the rolls were driven by frictional contact, the fact that they were conical prevented any grinding action and consequent production of slimes. The ore, which had been reduced

Mr. Commans.

in the rocking crusher was fed evenly into the machine, and passed successively beneath each of the three rolls. The pressure of each successive roll was adjusted so as to be a little greater than the preceding one, with the result that after the material had passed under the third roll it was sufficiently finely reduced and was washed off into the launder by a spray of water for further treatment. All high-speed crushers were, without doubt, unsuited for quartz crushing at the mines and out-of-the-way places, where breakdowns were difficult to repair. As long as all went well, the output of several of these high-speed crushers was satisfactory; but should a piece of drill steel, a bolt or hammer-head once get into the machine, a breakage of the flyers or beaters invariably took place, the renewal of which was a matter of considerable delay and expense, and would cause the stopping of the whole plant. With reference to the Crawford mill which was not mentioned by the Author, it might be pointed out that this mill undoubtedly possessed several novel features, and as a fine-crusher had given wonderfully good results. To pretend that any mill would crush and treat every class of material was a mistake that was often made, and in many instances blame had been laid on the machine, where it was really due to those employing it. To attempt to crush material finely in one operation was a very great mistake, and wherever attempted had invariably ended in failure. The Crawford mill was pre-eminently a fine-crusher, and in order to obtain the best results the material fed into it should have been previously reduced by a stonebreaker, which was the most economical form of coarse-crusher for reducing material down to say $\frac{1}{2}$ -inch to $\frac{1}{4}$ -inch size. The special features of the Crawford mill (*Fig. 25*) were:—The feed was central, not to one side, thereby ensuring an even wear of the roller-path. No screens whatever were employed, and a constant source of expense and trouble was thus removed. The crushed material instead of being discharged at the periphery of the machine where the swirl was great, passed out in a steady flow near the centre, so that there was no danger of any particles of gold being carried over with the tailings. A natural concentration was carried on in the machine itself by a current of clear water being admitted at the centre, passing over the surface of the mercury, and rising up through an annular slot below the crushing-path of the balls. The action of this rising current of water was to carry off all the material as fast as it was sufficiently finely reduced, and was light enough to pass out at the centre of the machine. Any gold that had been

freed from the quartz, or from sulphurets, owing to its greater Mr. Commans. specific gravity, could not be lifted by the rising column of water and sank down through the slot below the roller path, and became amalgamated with the quicksilver in the annular well. Further as the mercury-well was out of the swirl of the pulp, and as the water flowing over it kept any base mineral from coming in

Fig. 25.



CRAWFORD'S MILL. (LATEST TYPE.)

contact with it, there was no loss due to "sickening," and it was possible in these mills to treat refractory ores, which could not be treated in an ordinary stamp battery, with copper tables. The mercury was easily withdrawn from time to time to remove any amalgam, and fresh mercury added to the machine by means

r. Commans. of the pipe and funnel. In many ores the gold was so exceedingly finely disseminated that no amount of pulverizing in an ordinary stamp battery would eliminate this from its surrounding matrix. For such ores the Crawford mill was, undoubtedly, most suitable, since by it there was no difficulty in reducing the ore, so that it could pass a No. 120-mesh sieve. Stamps seldom pulverized finer than 40 to 45-mesh. The wearing-parts of these machines were rough castings, which could easily be renewed, and at far less expense than the tires of ordinary roller-mills. These machines were self-contained, easy of transport, and on arrival at the mine could be erected and put to work in a day or two. Clayey ores, which were very difficult to treat in a stamp battery owing to the slime produced, had been very successfully reduced by these mills, little or no gold being carried over with the tailings.

Mr. Edwards. Mr. R. EDWARDS pointed out that the ordinary gravitation-stamp was not such a clumsy and unmechanical machine as so many thought it to be. It was quite true that the total weight of a 10-head battery was considerable, and entailed in consequence heavy cost for carriage, besides that for the foundations and for erection. But even if £1,000 were allowed for these costs, the interest on that sum might easily be covered by the simplicity, freedom from breakdowns, and lessened wear and tear, which were the chief advantages that had made the stamp-battery an illustration of the survival of the fittest. Besides the advantages of its extreme simplicity, and of the fact that the stem of one stamp could be repaired without interrupting the work of the battery, the stamp-mill had the further advantage of being capable of dealing with any class of ore from the softest to the hardest.

Mr. Hadfield. Mr. R. A. HADFIELD stated that, according to the Author, Krom rolls, said to be made of the best open-hearth forged steel, had crushed more than 20,000 tons of ore before being worn out. It would be of considerable interest if the Author could give the chemical composition of such steel, especially as regarded the carbon contents; and, further, if he could state whether the rolls were put to work just as received from the makers, that is, beyond being machined, being used in the unhardened state. The firm with which Mr. Hadfield was associated had for several years been making considerable numbers of experiments with special material (manganese steel) for crushing-purposes, and although, for reasons in the manufacture, its introduction had not been on a large scale, the initial difficulties were now being rapidly overcome, and this manganese steel was being applied specially for

purposes where it was necessary to have hardness and great durability. Trials of stamp-castings of this material at the Tregurtha Downs mines, in Cornwall, had given exceedingly satisfactory results. Another special application of this material was tested at the well-known Penmaenmawr granite quarries, where much trouble had been experienced through the rapid wearing of the plates inserted at each side of the Blake stone-breaker to protect the parts of the machine between which the moving jaw works. A pair of ordinary steel sides was worn out in less than two months, whilst the manganese steel, after being in service for more than twelve months, had only worn $\frac{1}{4}$ inch, and was still at work. These trials referred to manganese steel in its cast state; in its forged state it had also given excellent results. Any material, which would enable more work to be obtained with less renewals, was of great importance in these times of severe competition in all branches of industry, and, therefore, these results obtained with manganese steel might be of interest. It would be of great service if the Author could give any further details as to the quality of steel hitherto found to be best adapted for crushing-work, and as to the particular points which seemed to him of most importance in preparing a material suitable to form parts of crushing and other machinery exposed to excessive wear and tear. The hardest material did not always prove to be the most durable.

Mr. H. N. HARVEY, having been intimately associated with the manufacture of various kinds of crushing, pulverizing and stamping machinery, wished to supplement the Paper by a few notes regarding the Husband stamper. This stamper had now been in use on various mines at home and abroad for upwards of twenty years, and thus it might be considered to have passed successfully through the experimental stage. In order to arrive at trustworthy data, he had gone closely into the performance of a battery of 4-heads of Husband's stampers, which were erected at Tregurtha Downs Tin Mine, Marazion, Cornwall, in 1883. These 4-heads were the only stampers on the mine. Various trials made from time to time on these stampers, over an extended period, showed that the four heads were together equal to crushing 100 tons per day of twenty-four hours, including all stoppages. The horse-power required for each head as indicated on the engine was 23·4. The size screens used were No. 36. The ore might be considered to be moderately hard, taking the Cornish ores as a standard. The cost of repairs and renewals for twelve months, including new shoes and dies, amounted to 4½d. per ton

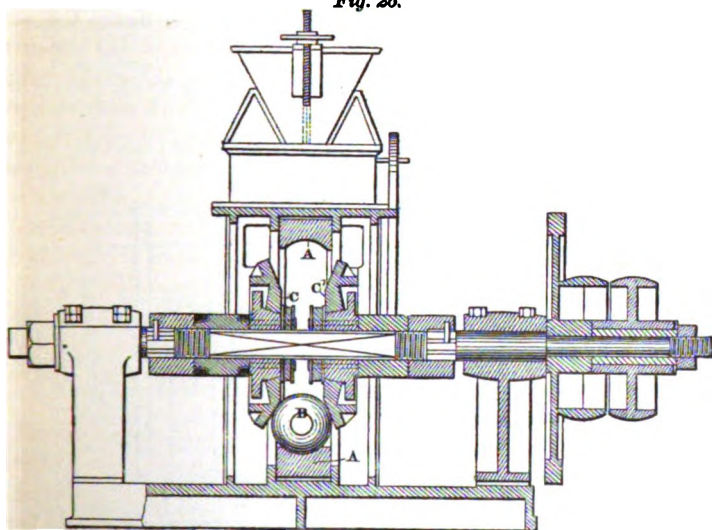
Mr. Harvey. of stuff stamped. This, he thought, compared in a most favourable manner with any similar type of machine in the market. Again a pair of lighter stamps erected at Callington tin mines, Cornwall, to supplement others of the same type previously erected there, had worked during the year ending February, 1892, with the following results:—Output per head per day of twenty-four hours, $21\frac{1}{4}$ tons; repairs of stampers throughout the year, nil. The character of the ore was hard tin capel, practically the hardest rock found in the county. The size screens used was No. 32. Taking the old Cornish gravitation-stamp as a standard of comparison, with the 4-heads of stampers at Tregurtha Downs Mine, it would require about 120 heads of the former, to obtain the same results. These heads would require 120 indicated HP. to drive them, would occupy a building 150 feet long, and would weigh, with wood framing, about 120 tons. The four Husband stampers required 93·6 indicated HP. occupied a building 25 feet long, and, with iron framing, weighed 30 tons. In the Table showing cost, capacity, &c., of stamps furnished by the Author, no record was given of the hardness of the ore stamped; but where a single head of 750 lbs. gravitation-stamps could pulverize 2 tons of ore per day, it might be safely asserted that the Husband stamps would pulverize 30 tons. With regard to the fineness of stamping, the Husband stampers would work well with any size perforations, provided the screens were made of best Russian iron or of copper. Screens of woven wire did not appear to stand well.

Mr. Jenkins. Mr. RHYS JENKINS thought that, although the classification of the machines described was perhaps a minor detail in the Author's Paper, it might be well to point out that that adopted appeared to be defective in some respects. In view of the fact that the term "roller-mill" was so extensively applied, in flour-milling and in milling generally, to the machines known in ore-milling as crushing-rolls, its use to denote mills of the Huntington type was objectionable. A new term, such as roller and ring mills, which would lead to no confusion, might readily be found for the latter. This class might include the Globe and similar mills, as well as the Howland pulverizers, but should not include edge runners. The term ball mill, or pulverizer, should be reserved for machines of the tumbling-barrel type, whilst the term pneumatic pulverizer did not cover the machines included in Class 6. "Impact pulverizer" would, perhaps, be a more suitable designation.

Mr. Kitto. Mr. C. W. KITTO urged that the objections to the Cyclops mill brought forward by the Author were not borne out by experience.

This mill would treat harder ore than the Huntington mill or the Mr. Kitto. Krom rolls would, and as its action was concussive and rolling, and not a grinding one, the gold was liberated from its matrix under the best conditions for amalgamation. Further, in the case of wet pulverizing, the cyclonic action in the mill, caused by the revolution of the ball and disks, induced a wave-action against the screens, so that the pulp was discharged as fast as ground, loss due to float gold being thus avoided. In dry pulverizing, the quartz was sucked out of the mill by the fan, the speed of which was regulated to suit the degree of fineness required. There was

Fig. 26.



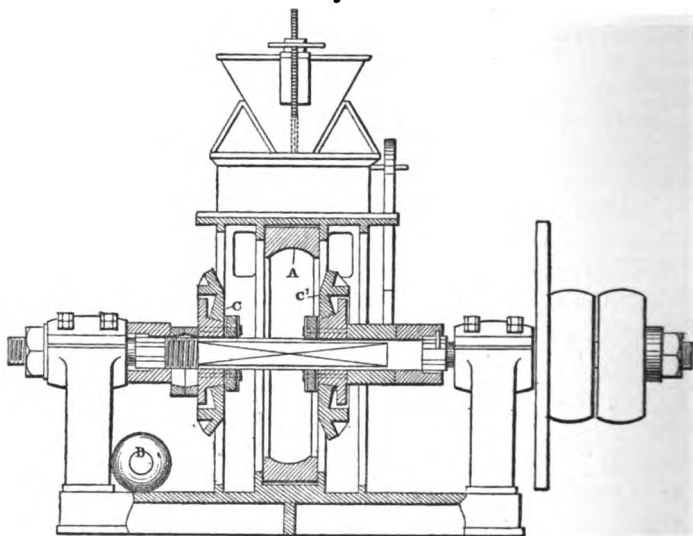
Sectional elevation, with ball in position. A, path; B, ball; C C', driving-disks.

"CYCLOPS" MILL.

no sieving, whether the fineness was 30 or 120. An independent authority, Mr. M. Eissler, in his treatise on the Metallurgy of Gold, stated that this was the only mill in which full advantage was derived from centrifugal action, and that by no other system could the work be done at so low a cost. The ball of this mill did effective work during the whole of its circuit. Though the Globe mill, in its original form, was undoubtedly complicated, this was not the case with the Cyclops mill, which numbered twenty parts as compared with twenty-six with rolls. The mill was adapted for both wet and dry pulverization. The principal feature in this mill was that the ball B, *Fig. 26*, which varied in weight from

Mr. Kitto. 16 to 300 lbs. according to the size of the machine, was caused to revolve at from 250 to 600 revolutions per minute in a vertical plane by the frictional grip of the driving disks C C', which were held by elastic buffers so as to permit the ball a certain amount of play in case it should in its trajectory encounter unusual sized pieces of quartz; and also by gripping the ball at different places or transverse diameters to cause it to constantly change its axis, thus insuring evenness of wear all over its surface. When the machine was set in motion, the ball by centrifugal force kept in

Fig. 27.



Sectional elevation, showing driving-disk slid back and ball removed.

"CYCLOPS" MILL.

close contact with the internal face of the path A A, crushing in its course the material interposed between it and the path. The rapidity with which the ball travelled, which, in a No. 1 sized mill running at 250 revolutions per minute was equal to nearly 3,000 feet per minute, caused the material to be carried round with the ball, thus insuring a continuance of effective work during the whole of its circuit. The working parts of the mill were enclosed, in the dry pulverizing mill, in an airtight casing, from which a fan sucked out the crushed material, the speed of the fan being regulated to suit the degree of fineness required. The material to be crushed was fed into the top of the mill through a

hopper which was fitted with an arrangement for regulating the feed. To avoid having to dismantle the mill when it was necessary to change a ball, the main shaft of the mill was fitted with a split sleeve which could be easily removed, and which permitted the driving disk on that side to be slid back and the ball removed, as shown in *Fig. 27*. The following Table gave the principal details of the three sizes of "Cyclop" mills made.

	No. 1.	No. 2.	No. 3.
Internal diameter of crushing path . . .	45 ins.	36 ins.	18 ins.
Width of crushing path	10 ins.	8 ins.	4½ ins.
Diameter of ball	13 ins.	10 ins.	5 ins.
Weight of ball	300 lbs.	130 lbs.	16 lbs.
Size of machine	88 × 58 ins.	78 × 48 ins.	44 × 24 ins.
Weight of heaviest piece	35 cwt.	18 cwt.	3 cwt.
Total weight	9 tons	5 tons	18 cwt.
Horse-power	16	9	3
Output per hour (60 mesh)	35 cwt.	20 cwt.	4 cwt.
Price for dry pulverizing	£450	£250	£60
" for wet "	£510	£300	£75
" combined wet and dry machine . . .	£510	£300	£75

Mr. S. R. KROM (New York) thought that the Author had endeavoured to be fair in his criticism of the merits of the various pulverizing machines under review. He could not, however, fully endorse the Author's remarks in relation to the Gates crusher. The wearing parts of that machine could not be considered durable. The objection was not to the large first cost, but to the trouble and expense of repair. In the matter of capacity, the Gates crusher had no advantage over a high-speed Blake ore-breaker. He was convinced that the best constructed ore-breaker and properly designed rolls were the most economical machines for crushing ore, and that all efforts to improve such machines should be directed to these, in order to bring them to the highest state of efficiency. In estimating the relative merits of rolls and other machines, it must not be forgotten that the screening capacity of pulverizing-mills and stamps was very small, and that the screens were subject to hard usage and rapid destruction. In the roller system, however, the screening was done independently of the crushing, and ample provision could be made for it. The Author's criticism of the Sturtevant mill was well founded. The power required was very great in comparison with that required in the case of rolls. The wear on the mill was excessive, and the grinding was effected by attrition—a feature which at once con-

Mr. Krom. demned it for pulverizing in cases where a granular condition of the pulp was required for lixiviation or for concentration.

Mr. Louis. Mr. D. A. LOUIS doubted whether the Author's objection to the Blake ore-breaker, that the product leaving the machine was of various and not uniform sizes, did not apply equally well to other crushing-machines. In the favourable opinion expressed on the Gates machine, the product was stated to be finer than that produced by a Blake ore-breaker; but there were no numerical data given to support this statement, or to show that the product was more uniform in size. Details as to the size of material fed in, and as to the proportion of various sizes obtained, would be of interest, as they would also be in the case of the Krom rolls, which were stated to pulverize 2 tons of gold-quartz per hour, without, however, any information being given as to the character of the comminution. The degree of fineness to which the rock could be pulverized by these rolls depended, according to the Author, on the number of times the coarser parts of the product were returned to the hopper. This statement was surely also applicable to Cornish rolls. In reference to the introduction of stamps into Cornwall, Carew, writing at the close of the sixteenth century, pointed out that dry-stamping was in vogue, but wet-stamping appeared to have been introduced into Cornwall shortly afterwards. Agricola made a statement that in 1512 a certain Duke George, of Saxony, liberally rewarded Sigismund Malthitz for replacing a dry-stamping plant by wet stamps invented by himself. Although the Author stated that the fine dust was unlikely to carry any estimable quantity of gold with it, Mr. Louis had seen fine dust collected from high ledges in a dry concentrating mill, and this proved to be rich in silver. Perhaps gold would not behave in this manner; but it was difficult to see why it should differ in this respect from silver, especially when the gold was finely disseminated in pyritic ores. In considering the various ball mills of the present day, one could not help thinking of the fate of their predecessors, all of which had eventually to give way to stamps. Among such mills might be cited the von Hermann mill, with balls in a revolving vertical drum; the Cochrane mill, with balls rolled in a horizontal path of cup-like section; the Wright mill, with rollers in a revolving vertical path; and the Stephan mill, similar in character to the last mentioned, but with rollers and path corrugated.

Mr. Meinicke. Mr. MEINICKE (Clausthal) was surprised to find that the Author had regarded crushing rolls as unsuitable for fine crushing by the wet process. That was not in accord with his own experience. In

a dressing floor belonging to the Mosel-Lahn Company at Trier, Mr. Meinicke. he had employed rolls which crushed per hour 3 to $3\frac{1}{2}$ tons of wet ore from the size of a bean down to 2 millimetres, all the ore that remained too coarse and did not pass through the circular holes, 2 millimetres in diameter, of the trommels being returned to the same rolls. The capacity was thus considerable, and the crushing of wet ores presented no inconvenience, if care was taken to submit them to a preliminary sifting so as to remove slime and to keep the rolls clean by playing on them with a jet of water. Rolls of 72 centimetres ($28\frac{3}{4}$ inches) in diameter and 29 centimetres ($11\frac{1}{2}$ inches) in width, made 80 revolutions per minute, and were pressed together by very strong and long india-rubber buffer-cushions, which in consequence of their length prevented a fracture of the rolls if a large unbreakable substance should happen to get between them. The rings might be turned in a short time without taking the crusher to pieces, while the rest of the machinery was still working. The rolls, which worked without cog-wheels, cost £230. and weighed $8\frac{1}{2}$ tons. The construction of the machine was so solid that rolls 15 inches in width could be inserted. If these figures were compared with those given by the Author in relation to the Krom rolls, it would be seen the satisfactory results obtained by the latter were probably less due to the special construction than to the fact that the rolls were very solidly built, and permitted a powerful pressure together of the rolls. The same result would also be arrived at if the various points brought forward by the Author in favour of the Krom rolls, were considered. (1) Good and well-fixed steel rings were also used in other crushing rolls. Further, the arrangement for turning the rings on the rolls mentioned above rendered that machine suitable for fine crushing, even if the best material for the rings was not available. (2) Toothed wheels had for many years been dispensed with in other crushing rolls, if they were required to revolve rapidly or if their diameter was sufficiently great. (3) The employment of the swinging pillow-blocks perhaps presented some small advantage to the manufacturer, but it had no appreciable influence on the action of the rolls, because the sliding friction of the pillow-blocks of other construction was extremely small in comparison with the forces exerted in pressing together the movable rolls. The fact that with swinging pillow-blocks the rolls always remained parallel, had a favourable action, inasmuch as the pressure on a specially hard piece of ore was somewhat increased, but an unfavourable one if the hard fragment did not give, because in that case the pieces in proximity were subjected to less pressure

Mr. Meinicke. than was the case in a crusher, the rolls of which could be placed somewhat inclined. (4) Powerful springs were also employed in other crushing-rolls in the same manner. (5) Satisfactory methods of feeding were also provided in other crushing-rolls. (6) Lastly, the housing for the rolls was unessential. From these grounds he concluded that, though he was completely at one with the Author in his opinion of the advantages of crushing by rolls, good results could also be obtained by rolls of other constructions than that of Krom, and he would go still farther in expressing the opinion that fine crushing was advantageous even for the treatment of wet ores, and of ores that are comparatively poor. In these cases, too, it was often advisable to effect the crushing by degrees, and either to avoid the production of fine slime or only to permit it after the valuable ore had been separated from the sands and coarse slimes. A mode of procedure such as this, which should give good results in the treatment of ores containing auriferous pyrites, would necessitate a careful dressing of the sands and slimes, and in consequence the erection of a large and costly dressing-floor, and the dread of such an expenditure was probably often the reason why, in spite of the attendant great loss, a simpler and cheaper method was preferred. This was obviously right when the life of the mine was short or uncertain. With reference to gravitation-stamps, he might mention that at Clausthal in the Hartz Mountains for fine stamping of the ore that has been crushed in rolls, gravitation-stamps with nine to eleven stamps in a battery were adopted. They were placed very close together (10 millimetres interval), and with a rectangular section the stamp heads had quite as great a capacity as rotating stamps, seeing that in the mortar-box there was but little free space, and with good material the amount of wear was comparatively small. By this arrangement, there was the advantage that a couple of batteries of eleven stamps each did not take up more space than two batteries of five stamps each. Care was taken to keep the height of water behind the screen the same as that in the mortar-box. This secured an economy in the consumption of water, and a longer life for the screen without diminishing the output of the battery. The stamps were, as a rule, of the single-discharge type. With two screens 20 per cent. more material could be stamped, but the consumption of water was greater.

Mr. Paxman. Mr. JAMES PAXMAN wished to confine his remarks particularly to the Huntington mill, with which he had had some little experience. The quartz to be used should be reduced to the size of a small walnut, or, better still, to that of a cob-nut. The

feed at all times should be automatic and regular. Care should be taken that the mill was not overfed. It should be fed so that it would comfortably clear itself. A sufficient quantity of water must be fed into the mill with the material to be dealt with. After a little experience the millman would know exactly how to treat the material, as very often two samples of ore required dealing with in different manners. No damage could arise to the mill itself from over-feeding, and he had never known a case where a mill had been broken through an accumulation of material in the centre. The action of the Huntington mill was one of crushing rather than grinding, and it was such that it would liberate the particles of metal without destroying their grain or turning them into float-gold. This mill was suitable not only for argillaceous and soft quartz, but also for the hardest and most brittle varieties. It had other great advantages, particularly that of delivery. As soon as the material was crushed it was delivered through the screens, and this constant delivery enabled the material to get thoroughly away. The mill could be made to discharge nearly all round, if desired, and in this case it would present a discharging surface very much greater than that which could be given to a ten-stamp battery. With reference to the saving of gold in the pan, this did not depend upon the quantity of gold contained in the quartz, but on the nature of the material. With quartz containing perfectly free gold, the proportion of gold retained was rarely less than 60 per cent., generally being from about 60 to 80 per cent. The Huntington mill could be easily put together at the mines, and fixed and started by a mechanic, understanding his work, in two to three days after its arrival. In this mill, as made at Colchester, the ring dies were of rolled steel, and he had never yet known one to break. The mill was, therefore, in all respects a thoroughly trustworthy one. The power used in the crushing of material through plates equivalent to about 30-mesh screen, was 10 indicated HP. This was crushing at the rate of 15 cwt. per hour; but, when indicating the engine-driving shafting only, the mill standing idle, he found it to be 3.73 indicated HP. Thus showing that the mill itself requires 6.37 indicated HP. In working the mill it was necessary to have an operator who thoroughly understood the use of such machinery, as the result depended very largely upon the way in which the mill was worked, and the quantity of water permitted to enter the mill. If too much was used the material became too thin, and did not work well upon the plates. Again, if an insufficiency of water was used, the discharge was too slow, and the result was not so satisfactory.

Mr. Reimers. Mr. E. REIMERS thought that the Author had not done sufficient justice to ball pulverizers, and notably to the ball mill constructed by Mr. Gruson, of Magdeburg-Buckau. During the past three years over four hundred of these mills had been made for Freiberg, Huanchaca, Potosi, and other mines in various parts of the world. The mill consisted briefly of a cylindrical drum, made internally of hard chilled cast-iron plates. This rotated on a shaft and was surrounded by double sieves. The mill was filled with a number of very hard steel balls. The ore was automatically fed into the hopper, and the pulverized product, which could be regulated to any degree of fineness, according to the number of the outer sieves with which the mill was supplied, came out below ready for being treated by amalgamation or concentration. This mill, he claimed, had successfully surmounted the objections raised by the Author as to the great wear and tear of such mills—objections which at first sight would seem natural enough, but which the careful construction of the wearing-parts, and the judicious selection of the material of which they were made, had completely overcome. Very satisfactory results had been obtained with these mills in the reduction of basic slag, and hard gold quartz, and the advantages of this mill would be evident from the following data:—A ball mill, 72 inches in diameter, could turn out from 25 to 30 tons of pulverized material of medium fineness per day, and required only 10 to 12 HP. to drive; it made about 25 revolutions per minute, and cost about £275. A mill, 84 inches in diameter, had an output of 45 to 48 tons per day, required 16 to 17 HP., made 20 revolutions per minute, and cost about £360. These results compared very favourably with those given by the Author for Krom rolls, and for the Huntington mill. The repairs, too, in the case of the ball mill merely consisted in supplementing the balls from time to time when they become worn. This mill, he considered, fulfilled most of the requirements named by the Author for an ideal pulverizer.

Mr. Smith. Mr. HAMILTON SMITH, jun., pointed out that gravitation-stamps have been employed for pulverizing ores from times of great antiquity; they were probably used by the Romans in the Iberian Peninsula, and were fully described in the earliest German literature on Metallurgy. At first the stem of the stamp was of hard wood, shod with iron, and had a square section. Soon after gold-quartz mining commenced in California—about the year 1856—round iron stems, to which a rotary movement was given by the moving cam, were employed in a mill at Grass Valley under the charge of Mr. Melville Attwood, father of Mr. George Attwood, Assoc. M. Inst.

C.E. The great merit of this invention was at once appreciated Mr. Smith. by gold and silver miners, and this form of gravity-stamp was now almost universally in use, except in Cornwall. In addition to this radical improvement, details in stamping had been so improved that a modern California gold mill would now pulverize per stamp in twenty-four hours 3 tons of hard quartz to a size which would pass through a slot $\frac{1}{16}$ of an inch across; whereas when he first became a resident of California in 1869, a duty of $1\frac{1}{2}$ tons per diem was considered excellent work. Many other methods had of late years been invented for the purpose of pulverizing ores; but to-day, by far the larger portion of gold, silver, and copper ores in the world was reduced by stamps, and in his opinion no other method of pulverizing hard rock or ore was likely to supersede stamping. This, he thought, was also the opinion of almost every practical man of large mining-experience. He therefore thought that the Author had attached undue importance to the merits of rolls, and various new methods of crushing, and had underestimated the advantages of stamping. Every few months one heard of some wonderful new invention by which quartz was to be crushed at the cost of a song, and by the aid of which worthless mines would become valuable; but at all the good mining camps, the stamps were still pounding away as they had been for centuries past, and as they would probably continue to do for centuries to come. The only rival of merit which the gravity-stamp had thus far encountered was the steam-stamp, which was really a steam-hammer, and which was now largely used in the reduction of copper ores on Lake Superior and in Montana. The Calumet and Hecla, and the Anaconda copper companies both used these stamps, and these two pulverizing-plants were by far the largest ever constructed, each of them having now a capacity of over 3,000 tons per diem. Neither of these two companies published accounts, so he was unable to give the costs of stamping per ton, but from personal observation he was convinced that this cost was very considerably larger at the Calumet and Hecla than it was with modern first-class gravity-stamps. The Treadwell Gold Mining Company in Alaska had a mill of 240 gravity-stamps, and for the year 1890-91 stamped 220,686 tons of hard quartz at an expense of 42 cents. (about 21 pence) per ton including costs of concentration. The screens employed had slots about $\frac{1}{16}$ of an inch across; water-power was used for about nine months of the year, and steam for the other three months. The mill was hardly a first-class one, the steam-engines were not of high class, coal cost £2 per ton, and white labour was paid about 14s. per day. The conditions for

Mr. Smith. cheap work were hence not particularly favourable. At the Calumet and Hecla mill, on the other hand, fuel was very cheap, the cost of labour was much more reasonable, and the screens in use had apertures $\frac{1}{2}$ of an inch in diameter. The Calumet officials, in comparing the two methods of stamping, insisted that, even admitting the superior economy of the gravity-stamp, for such a huge plant, the large amount of space required would be almost a fatal objection. This, by the way, was, he thought, the only well-founded objection to the gravity-stamps in the list of ten "defects" enumerated by the Author. The cost per ton of stamping-capacity for a steam-stamp plant was not very much larger than that of a gravity-stamp mill. The operating economical advantages of the latter were chiefly:—(1) The motor could be of large power, and of the most economical type known, whether of water or steam, while there must necessarily be a simple separate engine for each steam-stamp; (2) the wear and tear was much less; (3) minor accidents only delayed the working of a small fraction of the entire mill; (4) for fine stamping with a steam-stamp it was difficult to protect the screens. There could be no better proof of the advantages of first-class milling-machinery, coupled with judicious management, than the results obtained at El Callao. The old El Callao mill was of 60 stamps, and during the year 1882 pulverized 22,405 tons of quartz at a cost of 78·30 francs per ton. In 1885 a Fraser and Chalmers mill was erected. It consisted of 60 stamps weighing when new about 890 lbs. each; the drop was about 8 inches, and there were 94 drops per minute. The quartz was firm and hard, and was stamped through slots $\frac{1}{16}$ inch across. The total cost of milling for the year 1891 was 6·29 francs or 5s. per ton. Considering the high cost of labour, supplies, and fuel at El Callao this was an exceedingly low rate, including as it did 0·60 franc for share of general expenses, a charge not generally made to milling accounts. On the usual basis, therefore, the cost per ton for milling was 5·69 francs or 4s. 6d. The engine used was a compound-condensing tandem, supplied with steam by locomotive boilers with combustion-chambers, the steam-pressure being 145 lbs. During the year 1891, 1,589 English cords of wood were used for fuel, costing £3,492. This was equivalent to about 800 tons of good coal at £4 7s. per ton. In addition to supplying the power for stamping 58,949 tons of quartz, the engine did other work, so that only three-fourths of the power employed was used for milling. Consequently the fuel used per ton of ore stamped was equivalent to about 22 lbs. of good coal.

Mr. Taylor. Mr. HERBERT E. TAYLOR thought it was desirable to have some

particulars of the actual work done by the different machines Mr. Taylor. used for gold-quartz reduction. He had, therefore, noted a few particulars respecting the work of stamps and Huntington mills. The great variations in practice, which had been successfully adopted in different districts or under varying conditions, showed the necessity for a most careful consideration of the nature of the ore and of its gangue, before any decision could be arrived at as to the details of the machinery to be adopted. In California the weight of the stamps in general use varied from 250 lbs. to 1,100 lbs., the drop from $2\frac{1}{2}$ inches to 12 inches, the number of blows per minute from sixty to one hundred and twelve, and the screens from a 20-mesh to 60-mesh. In several cases, however, the screens were as large as $\frac{1}{4}$ -inch square mesh. The output of the mills varied from 15 cwt. per stamp-head to 13 tons, and the cost of renewals from $1\frac{1}{4}$ d. to 2s. $0\frac{1}{2}$ d. per ton of ore stamped. The average figures for one hundred and thirty-three mills, having two thousand two hundred and thirty-two stamps, were as follows: weight of stamp, 806 lbs.; drop, 6.06 inches; number of blows per minute, eighty-six and a-half; ore crushed (1 ton 19 cwt.), per stamp per day of twenty-four hours; the height of the discharge above the dies was 4 to $4\frac{1}{2}$ inches; the average screen used 37 mesh; and the average cost of renewals $5\frac{1}{2}$ d. In Colorado, where the ore had to be stamped much finer in order to free it from pyrites, the stamps weighed about 650 lbs.; they made twenty-six to twenty-eight blows per minute; they had a drop of 16 to 18 inches, a height of discharge of 13 inches, a 50 to 60-mesh screen, and an output of from 15 to 16 cwt. per day of twenty-four hours. Turning to Huntington mills, he found that at the Quaker mine, Calaveras County, California, a 6-foot mill driven at 50 to 55 revolutions per minute pulverized from 15 to 20 tons per twenty-four hours, so as to pass through angle-slot screens equalling 25 to 40-mesh screens. The lode-stuff was stated to be of a black, slaty nature, with quartz and a soft black gouge. At the Shaw mine, El Dorado County, a 5-foot mill, making 50 revolutions per minute, pulverized 10 to 12 tons per twenty-four hours, so as to pass through a screen equal to a 25 or 30-mesh. At the Mathines Creek mine, in the same county, a 5-foot mill pulverized 9 to 10 tons per twenty-four hours, so as to pass a screen equal to a 40-mesh. At the Monte Christo mine, Mono County, two 5-foot Huntington mills, running at from 65 to 75 revolutions per minute, pulverized 2 tons of ore per hour to pass a screen equal to a 40-mesh; 25 lbs. of quicksilver being charged into each mill at the commencement of the run, and about $\frac{1}{2}$ oz. more being added

Mr. Taylor. each half-hour. The tailings ran over 50 feet of blankets, and the concentrates were returned to the mill with the ore. The cost of renewals was not noted, but was believed not to exceed that in the case of stamps. At the Central mine, Shasta County, two mills pulverized 25 tons of ore per day of twenty-four hours, through a screen equal to 25-mesh; but whether 25 tons each, or for the two, was not stated, and no further particulars were given. At the Golden Treasure mine, in Tolumne County, one Huntington mill, 5 feet in diameter, was in use. The ore was crushed very fine before going to the mill, which treated 15 to 25 tons per twenty-four hours, using a slot-screen equal to a 35-mesh, about nine-tenths of the amalgam being recovered in the mill and one-tenth on the outside plates. The cost of renewals amounted to 1½d. per ton of ore treated. At the Spanish mine, Nevada County, California, there were four Huntington mills, three of 5 feet diameter and one of 4 feet diameter. They had treated a large quantity of material, and were reported to be doing good work, so that it might be interesting to go a little more into detail. The pay ore was found in a soft talcose slate, which contained many small veins and streaks of ferruginous quartz, carrying gold. The vein was worked by means of two tunnels and an open cut. The cost of mining in this way was 2s. 0½d. per ton of ore broken. The ore, a free-milling one, passed first to a Blake stone-breaker and then to the mills. The four mills ran at 58 revolutions per minute and pulverized about 4,000 tons of ore per month, or, in other words, 33 or 34 tons of ore for each mill per day of twenty-four hours, so as to pass through a slot-screen equal to a 20-mesh. After being charged at the starting of the run, quicksilver was put into the mills at the rate of ¼ oz. to each ton of ore, and the pulp passed, on leaving the mills, over the usual amalgamated plates. Of the amalgam recovered, 60 per cent. was obtained from the mills and 40 per cent. from the plates. The gold recovered from the mills was of a coarse grain, and the amalgam retorted about 40 per cent. The gold from the plates was very fine, and the amalgam yielded only 20 per cent. of its weight in gold on retorting. The loss of quicksilver was about ⅓ oz. per ton of ore. There was a tendency, if a large piece of rock happened to get into the mill, for quicksilver to be thrown out on to the apron. The cost of wear and tear of the ring-dies and roller-shells amounted to 2·05d. per ton of ore worked. The cost of screens was 0·6d. per ton, and this was considered heavy. The total cost of milling was 2s. per ton. The frequent necessity for readjusting the feed was stated to be the greatest difficulty in

working these mills, as there was no means of automatically Mr. Taylor. regulating the feed according to the quantity of ore in the mill, as is the case with stamp batteries. The value of the average yield of the ore was 3s. per ton; but, during a test-run that was made for one month, when 4,126 tons of ore were pulverized, the yield was 2s. 1½d. per ton, the superintendent stating that this was less than had ever been the case, while the loss of quicksilver was greater than usual. The tailings, which were thoroughly sampled throughout the run, assayed 3s. per ton in gold, showing therefore a working result of only 42·4 per cent. of the total gold contents of the ore. When the tailings were carefully ground and washed in an agate mortar, a few bright specks of gold were visible with a lens, but no quicksilver. Whether this loss was caused by trying to force too great a quantity of stuff through the mill, by the ore not being brought down fine enough, or by an excessive flow of water, whether in fact it was the fault of the mill or of the millman, there was no evidence to show; but the result of 42 per cent. saved could not be considered satisfactory. As bearing on the question of uniformity of size in the output, it might be noted that, whereas the mill-screens were equal to a 20-mesh, at least 50 per cent. of the tailings would pass through a 30-mesh sieve. Coming nearer home, he had taken the following figures from the daily returns of the running of three 5-foot Huntington mills on Cornish tin ore over a period of about twelve months. These mills were not worked to the best advantage, as they were driven from line-shafting, from which also power was taken to drive a stone-breaker, and a wire ropeway to bring up the ore from the adit-level's mouth. This line-shaft was driven by power transmitted by means of a wire-rope driven from a turbine, fixed some 600 feet distant, and this turbine also served to work the pumps to a depth of 60 fathoms. It was, consequently, almost impossible to keep up a uniform speed on the mills. The stone-breaker, too, did not do its work thoroughly satisfactorily, and frequently passed flat stones much larger than it should have done. The three mills pulverized 907 tons of lode-stuff (hard tin capel, with quartz), to pass a No. 36 Cornish gauge punched grate (equal to about a 15-mesh screen), in two thousand one hundred and nineteen hours, or at the rate of 8½ cwt. per mill per hour. The same mills pulverized 3,890 tons of lode-stuff, consisting mostly of chlorite or peach, with quartz, to pass Nos. 38 and 40 Cornish gauge punched grates (equal to 25 to 35-mesh screen) in four thousand six hundred and ninety-nine hours, or at the rate of 16½ cwt. per mill per hour. The average of the whole of

Mr. Taylor. the above crushing was 14 cwt. per mill per hour, the rate varying from 8 cwt. to 22 cwt. per hour according to the stone treated, the speed of the mills, and the care of the attendant in regulating the feed. The mills worked at speeds varying from 45 to 62 revolutions per minute, with an average for the twelve months of 55 revolutions. The wear and tear of the ring-dies and roller-shells was as follows: for the first 1,650 tons treated (mostly the hard stone), $10\frac{1}{2}d.$ per ton; and for the next 3,766 tons crushed (the softer stone), $4\frac{1}{2}d.$ per ton, or an average for the twelve months of $6\frac{1}{2}d.$ per ton. In none of the above cases was the actual power required to drive the mill given, but he had been informed that, in one instance, where a mill was treating 16 tons of medium gold-quartz per twenty-four hours, it required 11 indicated HP. to run it.

Mr. Wilkinson. Mr. W. F. WILKINSON commented on the absence from the Paper of a detailed description of the methods employed for obtaining the gold from the pulverized ore. There were a variety of ways for extracting the gold from gold quartz. Some advocated the practice of endeavouring to amalgamate as much gold as possible during pulverizing, naturally at the expense of the pulverizing capacity; others maintained that pulverizing should be carried out without regard to amalgamation. Some recommended rapid or coarse pulverizing and a concentration of the coarse sand, which might still have gold included or attached, by hydraulic classifiers for retreatment. The success of this method, presuming the extraction of the gold to be equal, would depend on whether the cost of collecting and retreating the coarse sands was less than the difference of cost between coarse and fine stamping. The pulverizing machine would be influenced by the requirements of the system of amalgamation adopted. With regard to the Huntington mill, he agreed with the Author that for certain ores, particularly soft ones, and for small mines, this mill was of great value. As evidence of its practical success, he might mention that he had seen it working on silver ores at the Santa Eulalia Mill, Mexico, where gravitation-stamps were formerly used. Here the Huntington mill was said to work more economically than stamps. There was one point connected with the Huntington mill not mentioned by the Author, and that was the difficulty of feeding it properly with automatic feeders, when the ores varied in hardness. The Huntington mill, unlike the stamp-battery, had nothing to regulate the feed. If the ore was not regular in hardness, it followed that the mill was liable to get choked when hard rock was being fed in; for though the automatic feeder would continue to feed hard and soft rock equally fast, the mill would not be able

to pulverize the hard so quickly as the soft. With regard to the Mr. Wilkins question of the superiority between stamps and rolls, the point of chief interest in the Paper, he had been much disappointed that no practical working-results of rolls in a gold-quartz crushing mill had been brought forward. He agreed with the Author's list of objections to the stamp battery, and was glad that among these objections he had not thought the great noise attending their use beneath notice. In a stamp-battery, to give directions or to gain information, except by dumb show, were equally impossible. In spite, however, of their disadvantages stamps had proved, in all parts of the world, most useful and efficient machines, and before rolls were introduced to take their place for fine crushing, he thought further proof was needed to show that they were as economical as stamps. The figures of the Bertrand mill, quoted in the Paper, figures which had been repeatedly quoted before in similar Papers in favour of Krom rolls, were apt to be misleading, as far as they were used for making a comparison with stamps. The Bertrand ores were crushed through a 16-mesh screen for the lixiviation process, whilst gold-quartzes required to be passed through a much finer screen, not usually less than 30-mesh and more often 40-mesh. Moreover, at the Bertrand mill, the rolls were tried with finer screens, but the results were unsatisfactory, the reason being that the capacity was reduced, owing to the difficulty experienced in getting the ore to pass the screen. Again, at the Haile Gold Mine, South Carolina, the Krom rolls were tried for fine crushing and proved a failure. They became surcharged, threw their belts, and wore badly. Although for very fine crushing Krom rolls did not appear to have been a successful rival to stamps, there could be no doubt that, where very fine crushing was not essential, they provided a most efficient machine. They could also be used with advantage in crushing gold-quartz in mills where some system was employed for concentrating the coarse sands for retreatment. It was well known that in crushing ore through a screen of any size, a large percentage would pass through a much finer screen. In crushing, therefore, through a 16-mesh screen, which Krom rolls could do satisfactorily, it was probable that a large amount would be as fine as if it had been crushed by stamps through a 40-mesh. The coarse sands would have to be concentrated and reground; but would probably form only a small percentage of the original bulk of ore. In conclusion, he was of opinion that the losses that occurred in gold-milling were more likely to be reduced by improvements in the amalgamation part of the process rather than in its crushing part.

Mr. Wilkinson. The losses would be reduced by a more careful attention to statistics than was, except in the case of a few mines, at present given. Careful sampling in all parts of the mill would show where improvements might be made.

ADDENDUM, APRIL 22, 1892.

The Royal
Commission.

THE ROYAL COMMISSION, appointed on July 15, 1889, to enquire as to the best mode in which assistance could be rendered to develop the auriferous resources of the colony of Victoria, has recently published a voluminous report, a copy of which has been presented to the library of the Institution since the reading of the Paper on "Gold-Quartz Reduction." As the evidence set forth in the report was tendered by some of the most experienced mining-engineers in the colony, it has been thought that a brief summary of the information given in relation to gold-quartz reduction would be of value as representing the opinions of Australian experts on this subject. The reduction of the auriferous gangue should, the report states, first be effected, where possible, by the use of stone-breakers, and the broken-up ore should be fed automatically into the reducing appliances, either wet stamps, Huntington's centrifugal roller quartz-mill, Husband's medium pneumatic stamps, the Ball direct-acting steam-stamps for poor, hard stone, or a wet-working Globe mill (Lansell's Bendigo mill). Instead of wet-stamping, dry pulverizing in stamps or rolls might possibly be resorted to with good results in districts in which there is a scarcity of water. The Commission makes no definite recommendation in regard to gold-quartz reduction, except that stone-breakers should be more generally employed. Their value, from an economical point of view, has been established beyond question, and they should be used in all cases where large quantities of ore have to be treated.

9 February, 1892.

HARRISON HAYTER, Vice-President,
in the Chair.

16 February, 1892.

ALFRED GILES, M.P., Vice-President,
in the Chair.

Both of the above meetings were devoted to the discussion of the Paper by Mr. A. H. Curtis on "Gold-Quartz Reduction."

**LIST OF MODELS, &c.,
EXHIBITED AT THE MONTHLY RECEPTION, 26 JANUARY, 1892.**

Exhibitor.	Objects.
APPLEBY BROTHERS . . .	Model of Stamp-mill, with actual parts (shoe, die, and cam). Photographs (8) of Mining-plant.
EDWIN J. BALL, Ph.D. . .	Gold-washing Pans (3). Samples of Auriferous Quartz and of Native Gold.
H. BAUERMAN, Assoc. M. Inst. C.E.	Specimens (15) of Native Gold and of Auriferous Veinstones.
W. WORBY BEAUMONT, M. Inst. C.E.	Model of "Coles" Double-action Stone-breaker.
CLARKSON - STANFIELD CONCENTRATOR COMPANY.	Model of "Clarkson-Stanfield" Concentrator.
COMMANS & CO.	Model of "Commans" Stamp-battery.
DAVEY, PAXMAN & CO. . . .	Roller and Yoke (actual parts) for "Huntington" Mill.
THOMAS DOWRA & SON . . .	Model of Diamond-drill Machine. Samples (6) of Cores, &c.
FRASER & CHALMERS	Model of "Huntington" Mill.
GATES IRON WORKS	Small Gyratory "Gates" Rock- and Ore-crusher, with spindle, eccentric-box, &c. (An exact working model of the machines used in America and Australia).
GLOBE MILL COMPANY	Samples of Gold-quartz.
HARVEY & CO.	Model of 5-head Stamp-battery ("California" type). Model of High-speed Revolving 5-head Stamp-Battery.
EDWIN COLLETT HOMERSHAM, Assoc. M. Inst. C.E.	Photographs (2) of 120-head Stamp-mill in course of erection for the Langlaagte Estate Gold Mining Company, at Johannesburg.
RICHARD HORNSBY & SONS . .	Model of 10-head Stamp-battery, with actual parts (shoe, die, cam and tappet).
INGERSOLL-SERGEANT DRILL COMPANY.	Model of Air-cylinder of the "Ingersoll-Sergeant" air-compressor.
T. B. JORDAN & SON	Photographs (2) of Plant used for Jordan's "Centrifugal" gold-process.
BEDFORD McNEILL, Assoc. R. S. M.	Photographs of the Mining Town of Ouray, the Las Animas Cañon on the Denver and Rio Grande Railroad, and the Chatacoga loop on the Silvertown Railroad, all in Colorado.

Exhibitor.	Objects.
H. R. MARSDEN	Sectional Models (2) of Stone-breaker and Pulverizer.
PERCY J. NEATE	Working Model of "Adair-Cruikshank" Grinding-mill for treating tailings.
ROBEY & CO.	Model of "Crawford" Gold-extractor.
SCHOOL OF MINES, ROYAL COLLEGE OF SCIENCE.	Specimens (12) of Gold Ores.
SCIENCE AND ART DEPARTMENT (South Kensington Museum).	Model of Appliance used in Mexico for incorporating mercury with silver ores.
	Model of "Baxter" Ore-crusher.
	Small "Pelton" or "Hurdy-gurdy" Water-wheel.
BOWEN, SCOTT & WESTERN .	Drawings (2) of "Krom" Single-roll Crushing-plant.
	Samples of Ores crushed by the "Krom" Mill.
ERNEST A. SMITH	Gold-washing Pan.
	Representative Examples of the forms under which native gold is found.

23 February, 1892.

GEORGE BERKLEY, President,
in the Chair.

(*Paper No. 2584.*)

“The Bishop Rock Lighthouses.”

By WILLIAM TREGARTHEN DOUGLASS, A.K.C., M. Inst. C.E.¹

THERE are few if any lighthouses of more importance to sailors, or of more professional interest to the engineer, than the Bishop Rock. The scene of the disaster to Sir Cloudesley Shovel's squadron in 1703, may well be an object of popular curiosity, even if there had not been besides, many a catastrophe there fatal to ships and their crews. The recent works undertaken at this rock have a special interest for mariners, as those operations have almost completely nullified what was once a great peril, dreaded by seafarers of all nations. Accordingly a brief record of the lighthouses erected on the westernmost landfall rock of the Scilly Islands, between the years 1847 and 1888, embracing, together with recent improvements, the iron-pile and granite structures designed by the late James Walker, F.R.S., Past President Inst. C.E., cannot fail to be of interest to the members of the Institution.

When in 1846 the Corporation of Trinity House had under consideration the erection of a lighthouse on the Bishop Rock, it was decided to install within it one of the best lights then available, viz., that from an illuminating apparatus of the first order of “Fresnel” for a fixed light, having at its focus a 4-wick “Fresnel” burner consuming colza oil, and giving an intensity in the beam of about 6,500 standard candles, with a nautical range of 15½ miles. It was also determined to provide this lighthouse with a bell weighing 5 cwt., as a signal in foggy weather. The largest passenger ships at that time in existence, trading between America and British ports, did not exceed 2,000 tons register, with a maximum speed of 9 knots. If this state of things is contrasted with the requirements of navigation at the present day for ocean steamships having a tonnage at least five times as great as those

built in 1847, with a speed in some instances exceeding 20 knots an hour, it will be readily perceived that not only had it become a matter of absolute necessity to give the mariner an increase both in the power and range of the light in clear weather, but that he should be more effectively warned of his proximity to danger, when running at high rates of speed, with the surrounding atmosphere impaired by rain, haze, and fog.

The perfection to which deep-sea sounding apparatus, and ships' compasses have of late years been brought—largely due to Lord Kelvin, President of the Royal Society, Hon. M. Inst. C.E.—and the accuracy and completeness with which the depths of the ocean and the variations in the bottom of the sea have been ascertained, decrease in a large measure the risk incurred by commanders of ocean steamers in making a landfall. Notwithstanding these recent additions to science, wrecks are unfortunately of frequent occurrence; and it is with these facts that lighthouse authorities have to deal in designing modern lighthouses, and installing the requisite high powers of light and sound signals.

Between the years 1680 and 1790, the Scilly Islands, which cover a rock-bound area of 35 square miles, had for their sole coast illumination an open coal-fire placed on the summit of a tower on the island of St. Agnes, nearly 5 miles within the outer dangerous reefs and rocks. The "cresset" which formed a part of this primitive Pharos, might have been seen recently in the grounds of the Royal Naval Exhibition. The Corporation of Trinity House, in the year 1790, replaced this primitive apparatus by the first revolving catoptric oil-light established on the coasts of Great Britain. This has undergone successive improvements, though the original type of illumination has been retained.

The Bishop Rock, which probably derives its name from its original resemblance to a bishop's mitre, is of very hard pink-coloured granite. The rock is just covered at high-water ordinary spring-tides. This isolated danger, surrounded by from 20 to 25 fathoms of water close alongside, is situated at a distance of 7 miles from the principal island of the Scilly group in a south-westerly direction, and is exposed to the full force of the North Atlantic ocean with a "fetch" of 3,600 nautical miles. From this fact, and from the instances of heavy seas striking the buildings related in this Paper, it will be understood that in stormy weather the rock is subjected to very severe wave shocks, and that any structures founded upon it must depend for their durability on solidity of construction, excellence of material, and perfection of workmanship. A series of observations on heavy waves encountered

at this station were made in the year 1847 by the late Mr. N. Douglass,¹ then the superintending Engineer to the Trinity House. Mr. Douglass related to the Author that, during the construction of the first lighthouse, an iron column, weighing 3 tons, was landed on the rock during the progress of the iron tower, but the weather did not admit of its immediate erection. The foot of the column was landed on a bench of the rock, and securely lashed to eyebolts by $\frac{1}{2}$ -inch chain; and its upper end was secured to the framing of the tower, the column occupying a vertical position. On sailing round the rock three days later, it was observed that the column had been tossed up 20 feet on to the top of the rock, and was swaying about horizontally like a piece of timber, being held by the lashings at its upper end only. On landing at the rock some days later, it was found that a blacksmith's anvil, weighing $1\frac{1}{2}$ cwt., had been washed out of a hole, 3 feet 6 inches deep and 2 feet in diameter, prepared for the column. Certain facts, moreover, came under the Author's personal observation during the erection of the improved granite tower, which may assist in realizing the difficulties attending the building of the structures upon the westernmost rock of the Scilly Islands. During a severe north-west gale, the solid waves are impelled over the inclined surface of the rock to a considerable height, and thence in broken masses up the shaft of the tower, a further portion being driven in sheets over the lantern vane. A heavy steam-winch bolted to the masonry of the landing platform, at a level of 22 feet above high water, and protected by masonry breakwaters, was completely wrecked and washed away, the bolts and portions of the bedplate alone remaining. Further, a 12-inch iron leading block, shackled direct to the landing jib and fixed at an elevation of 60 feet above high water, was struck by the sea and borne off, owing to the fracture of the $1\frac{1}{4}$ -inch shackle which alone remained. Again, an iron cradle, which was securely guyed, and suspended by $\frac{1}{8}$ -inch chain slings beneath the lantern gallery, at a height of 115 feet above the highest level of the sea, was torn from its attachment. As illustrating the violence of the sea as it strikes exposed positions in the islands of Scilly, another incident may be recorded. On the morning following a heavy storm from the north-west in the winter of 1886, the Author had occasion to visit Round Island, lying 5 miles distant from the Bishop Rock, where a second lighthouse was in course of construction under his supervision. Large masses of water had been driven over the summit of this rocky island, which is 130 feet in

¹ Minutes of Proceedings Inst. C.E., vol. xv., p. 8.

height. On the flat roof of the dwelling-house, the Author discovered a living limpet, and a number of small stones weighing $2\frac{1}{4}$ ounces, waifs and strays carried by the force of the sea to an altitude of 143 feet above high water. Such facts as these will explain much, which would otherwise be almost difficult of credence, in the following narrative.

At the level of low-water spring-tides, the Bishop Rock is 153 feet long and 52 feet broad, from which level it runs down sheer and steep some 20 fathoms or more. Thus it will be readily understood how, in the year 1845, the opinion was generally entertained that the width of the rock was not sufficient for the base of a stone tower, which should be strong enough to withstand heavy wave shocks. Consequently it was decided that an open structure of wrought- and cast-iron should be placed upon the Bishop Rock (Plate 4, Fig. 1). This work was begun in 1847 under the direction of Mr. N. Douglass. The iron columns, strengthened by strong wrought-iron cores, were all deeply sunk and lewised into the rock; and these were designed to offer the least resistance to the passage of the sea between them. Ingress to the living-room, stores, and lantern of this lighthouse was to be obtained through the centre column. After overcoming many difficulties in erection, and at the end of the fourth working season, the tower was ready for the reception of the lantern and illuminating apparatus. In that state, the structure was confidently left to resist the winds and the waves of the coming winter. A heavy storm occurred during the night of the 5th February, 1850, and when morning broke the iron lighthouse had been swept away, and nothing remained above the surface of the rock, except short portions of the main columns. This disaster was doubtless due to the heavy seas sweeping over the rock at an elevation considerably higher than had been estimated, and thus striking with their full force the larger surface of the upper portion of the structure, intended for the residence of the lightkeepers, and for the storage of their provisions, fuel, &c.

Thus the whole matter of placing a lighthouse upon the Bishop Rock came up for reconsideration by the Trinity House; and on the recommendation of their engineers, it was determined to raise a granite tower to replace the iron one (Plate 4, Fig. 2). This work was proceeded with in 1851, again under the direction of Mr. N. Douglass. On the most exposed side of the rock, at the level of 1 foot below low-water spring-tides, the lowest stone was laid—for thus only could the greatest possible diameter of the base permitted by the area of the rock surface be obtained. In

spite of many efforts to lay this stone, the work was not accomplished before the end of the year 1852, although work at a higher level was proceeded with. During the construction of the building, great difficulties were experienced in landing by manual labour the stones conveyed to the rock in barges, which were towed from the workyard at St. Mary's. The year 1858 saw the tower finished, and a dioptric fixed white light exhibited, as intended for the former lighthouse.

In brief space, however, the Trinity House were further reminded of the extreme exposure of the tower to heavy seas, a notable circumstance bringing this fact vividly before them. Fixed 100 feet above high water, on the lantern gallery, was a 5 cwt. fog bell. During a severe storm, it was torn from its bracket, to which it was firmly bolted, and was washed away together with the flagstaff and ladder lashed to the gallery. A portion of the fog bell was afterwards found in a cleft of the rock, and is preserved at the Trinity House. When a hurricane of this type was raging, the tower vibrated considerably; articles were shaken from the shelves in the rooms, and the prisms of the dioptric apparatus fractured. Later on it was discovered that some of the external blocks of granite, situated a few feet above high water, had been split by the excessive strain imposed on the building. Acting upon the advice of their engineer, the Trinity House, in the year 1874, strengthened the tower from top to bottom by bolting heavy iron ties to the internal surface of the walls, and connecting them through the floors. Nevertheless, after a violent storm in 1881, there was again evidence that the heavy strains of the sea had caused further damage. In certain instances, pieces of granite weighing $\frac{1}{2}$ cwt. were split from the face of the exterior blocks, a few feet above high-water level. The Trinity House therefore resolved to strengthen and improve the tower.

In view of the increasing demands of navigation, and the number of vessels wrecked on this coast in foggy weather, the Trinity House decided not only to strengthen the lighthouse, but to thoroughly improve the internal accommodation, the illuminating apparatus and fog-signal, and to effect such alterations as should place the tower in the foremost rank of rock lighthouses. At the same time, an efficient light was to be maintained on the site during the whole of the operations. In carrying this decision into effect, the engineer submitted the improvements shown in Plate 4, Figs. 3 and 4. These consist of an outer casing of masonry, dovetailed horizontally and vertically from the foundation courses

of the original granite building to the level of the service-room floor; above this point, the structure was entirely removed, and four new rooms added, the walls of these rooms being built of through stones. The lantern and illuminating apparatus surpass in power all similar installations to be met with at the present time in rock lighthouses. The height of the mean focal plane of the light above high water of ordinary spring-tides, was increased from 110 feet to 146 feet; and the nautical range was thus extended from 16 miles to 18½ miles.

On the completion of the new Eddystone lighthouse in 1882, the plant used in its construction was taken over at a valuation and conveyed to the Scilly Isles, where a plot of ground for a workyard was leased, adjacent to St. Mary's pier. A portion of this plot was occupied by the Trinity House during the construction of the former towers on the Bishop Rock. The Author was appointed resident engineer, with responsibility for the due execution of the work. Offices, workshops, and overhead travellers were erected, and a line of rails laid down between the workyard and the steam-crane set up on the pier to aid in loading and discharging material. The twin-screw steamer "Hercules," of 130 tons net register and 45 NHP., built in 1870 for service at the Great and Little Basses lighthouses, Ceylon,¹ was taken over as a portion of the plant.

The granite blocks forming the casing of the tower and the upper portion, were obtained by contract from the Eddystone Granite Quarries at Delank, Cornwall. The blocks were carefully dressed in the quarry, and erected temporarily in sections. Each stone up to, and including course eight, had a male dovetail, 6 inches in depth at its inner end, to insure a perfect connection with the granite tower; and, moreover, it was dovetailed to the other blocks of granite with which it was connected. The blocks up to, and including the twentieth course, were each of them further secured—after being bedded and grouted in Portland cement and clean sharp granite sand, in equal proportions by measure—by two 1½-inch Muntz metal bolts, fox-wedged, passing through the upper stone and 9 inches into the stone below, as used in the first granite tower. In consequence of the frequent sudden rise of the sea, these bolts were found to be especially necessary for securing the lower stones from displacement by the waves until the cement had thoroughly hardened. Below course twenty-five, the joints, both horizontally and vertically, broke joint with those in the

¹ Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 50.

masonry of the old work. It was this portion of the old tower which had given the most significant tokens of weakness, although there was evidence, on cutting into the walls, that the whole of the masonry work had been most carefully and perfectly executed. The quality of the work was further proved by the fact that no evidence existed of water having been driven into the joints. Hydraulic puzzuolana mortar, carefully prepared, had been used throughout the work above high-water spring-tides; below this, all the masonry was set in Roman cement.

The outline of the improved tower (Plate 4, Fig. 3) was designed to meet the conditions imposed by increased height, and so as to utilize fully the utmost extent of foundation afforded by the rock. It was also intended to give the utmost additional strength to the walls, especially at those points where weakness had shown itself, and to preserve as low a centre of gravity as possible. The cylindrical base, 41 feet in diameter, was carried up nearly vertically to a height of 40 feet above the foundation, and terminated in a landing platform, approached from the rock by gun-metal cleats. In this case it was found necessary to carry the cylindrical base to a greater height above high water than the base of the new Eddy-stone, where this form of construction was first employed; and experience proves that the platform is at the most efficient level for the safety of the lightkeepers when landing supplies, &c. When the waves break against the rock or vertical base, and are driven in sheets of water over the platform, the relief of the tower or landing of stores is an impossibility, because of the danger a boat incurs in approaching the rock. From the inner edge of the platform above-mentioned, and at a diameter of 32 feet, the curve of the tower springs, taking the form of a concave elliptic frustum, with generating axes of 237 feet and 62 feet respectively. This curve terminates in a bold cavetto, carrying the gallery on which the lantern rests.

The granite blocks forming the dovetailed casing and upper portion of the tower, ranged in weight from 2 to $3\frac{1}{2}$ tons. These were conveyed to the tower by the twin-screw steamer "Hercules," each block being carefully stowed on elm rollers in the hold. To the southward of the rock (Plate 5, Fig. 6)—a position selected owing to the great depth of water and the space afforded for manoeuvring—three moorings were laid down, consisting of 35 fathoms of $1\frac{1}{2}$ -inch ground chain, and 1-inch open link upper chain, shackled at the upper end to a 5-foot spherical steel mooring buoy, and at the other end to a 2-ton cast-iron sinker, which was again attached by 20 fathoms of $1\frac{1}{2}$ -inch chain to a 2-ton backing sinker, to prevent

the first sinker drawing home towards the rock when the vessel was moored and landing stone. During the winter months, the wear of the chain on the rock bottom was so great that it was found necessary to relay the moorings every three months. Three strong iron mooring stanchions were fixed on the rock. The steamer, on her arrival at the "Bishop" was moored as follows. The head mooring buoy was picked up, and a 13-inch coir hawser made fast to it. The vessel was then backed astern, and warped up to the rock by a small hawser. Two 13-inch coir hawsers were made fast to the mooring stanchions, and the slack hauled in by the deck winches. Two additional 9-inch coir hawsers were afterwards run out to the remaining head mooring buoys, to maintain the vessel in her position against a strong beam tide. The assistance derived from the use of twin screws in berthing a vessel in a tide-way, with an adverse tide running at springs at a velocity of from 4 to $4\frac{1}{2}$ knots per hour, cannot be over-estimated. When a moderate ground sea has set in after the vessel has been secured in position, the back send from the rock was occasionally so great that the coir hawsers yielded to the excessive strain, and parted one after the other.

It was found convenient, during the progress of the operations, to land the working party by means of a manilla rope attached to a single-whip winch standing on the gallery of the tower. In this way the working party usually passed to and fro from the landing boat, which was lying under oars at a distance of from 10 to 15 fathoms from the rock, clear of the heaviest of the broken water, and free from risk of being stove in. No serious accident occurred to either of the landing boats, either by collision with the rock or by overturning, although they frequently encountered heavy seas when they had on board a full complement of men. The working party employed on the rock usually numbered thirty, and was actively engaged, when the state of the tide and weather permitted it, in dressing back the face of the granite rock (Plate 5, Fig. 5), and cutting out dovetails for the safe bonding of the new masonry. The work was necessarily very tedious; and progress in erection was much less rapid than would have been the case with an entirely new building. The mode of operation was as follows:—Holes were drilled by manual labour in the face of the tower, then the granite was plugged by means of steel plugs and feathers, and the dovetails were eventually dressed to template by double and single-handed cast-steel points. One mason and one hammerman worked together preparing for each block of the new masonry, and on an average completed their work in rather under

two days for a dovetail stone, the dressing for a stone having no dovetail at its inner end occupying the remainder of the second day.

On completion of the dovetailed casing above mean-tide level, twelve workmen were lodged at the tower to expedite the work by taking advantage of every opportunity to proceed with dressing back the surface of the tower, when it was inexpedient, because of heavy seas, to land the whole of the working party on a rising tide. The workmen stationed at the tower were also of service in the erection of the setting cranes and temporary illuminating apparatus. This work could be proceeded with in moderate weather. The work of dressing back the tower to receive the new masonry between low-water mark and half tide was of a dangerous character, in consequence of the occasional very sudden rolling in of Atlantic waves when least expected. Life-lines were made fast to a chain encircling the tower, and placed beside each workman. Frequently the sea running up the surface of the rock completely buried the men. For the security of the workmen whilst employed between the summit of the vertical base and course sixty-two, and also in order to provide more room than the upper surfaces of the new blocks allowed for carrying out operations at this height, foot boards were fixed to brackets secured in the masonry. In connection with the brackets, a strong manilla rope net was secured to the bracket stanchions and drawn tight round the tower beneath. The workmen had entire confidence in this measure of protection; moreover, the net could be put up and removed in about a quarter of an hour. On completion of the masonry, the number of workmen residing at the tower was considerably augmented, to expedite as far as possible the fitting up of the illuminating apparatus, lantern, wrought-iron partitions, stairs, shutters, machinery, and general internal arrangements.

The blocks of granite forming the dovetailed casing were landed direct from the twin-screw steamer by means of her own steam-power, as previously described in a Paper by the Author on the new Eddystone lighthouse.¹ Frequently the blocks of granite, on emerging from the water under the stern of the vessel, were struck by a heavy sea, causing them to swing over a considerable number of degrees. The force of the swinging movement was further increased by the heavy rolling of the vessel. To meet this difficulty, the block was again lowered into the water to bring it to a state of comparative rest. Then advantage

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 31.

was taken of a temporarily smooth sea to proceed with its landing. At the tower, heavy coir mats were placed to receive the block to avoid damage, and to break the concussion when the winch was reversed in order to land it. It will be easily understood that a sudden rise or fall of the vessel on a wave would frequently cause the block to rise or fall 6 feet. As the work progressed, the blocks were landed on the vertical base platform, and eventually on a temporary stage at the level of the entrance door (Plate 5, Fig. 5). Above this level, it was not found expedient to land the stones direct from the vessel upon the new masonry, as the heavy seas which were occasionally encountered tended to throw an excessive strain upon the central crane and chain falls. No damage occurred during the landing of the blocks after leaving the steamer. One block was, however, lost. It was thrown over the rail of the vessel amidships, from the deck truck upon which it had been deposited. This accident was due to a very heavy beam sea which caused the vessel to roll abnormally. As the loss occurred at the end of the working season, it fortunately occasioned no delay in the work.

A hoisting and setting crane was erected on the lantern gallery, capable of transversing the complete circle. The blocks were lifted by this crane from the landing position, and traversed as required to their setting position, where they were deposited on a cement bed. This specially designed crane was actuated entirely by hand-power, and proved a very efficient machine in setting the whole of the new masonry from the foundation up to course sixty-two, when it was removed and superseded by the central crane. This crane consisted of a hollow wrought-iron mast and topmast, 40 feet in height, carried in iron partners and timbering in the rooms, and stayed by guy chains. Two wrought-iron jibs were carried on the mast for hoisting and setting the blocks. The setting jib, traversing a complete circle, was provided with a winch. The topmast carried an iron pole, to which was attached a Trinity House floating-light lantern, in which was maintained, during the progress of the work, a powerful double flashing catoptric light. The crane, together with the lantern and illuminating apparatus, was raised by hydraulic jacks to its successive positions as the works progressed. In order to facilitate the hoisting of the blocks from the position at which they were landed to their final position in the tower, a steam-boiler and winch were bolted to the vertical base platform, and protected, as far as possible, from the direct force of the waves by masonry breakwaters. The whole of the blocks comprising courses sixty-three

to ninety-one were thus hoisted by the steam-winch, between the 26th of June and the 30th of August, 1886, at the rate of one, and occasionally two courses per day, as circumstances would permit. To avoid giving the hoisting jib unnecessary overhang, a frame carrying two elm rollers was placed behind each stone, which admitted of its passing up over the face of the tower without damage. Before the winch and boiler could be removed to the shore after completing the work, they were swept away during an equinoctial gale.

The strengthening and improvement of the tower by means of an outer casing of dovetailed masonry, the addition of three rooms in height, and the fitting up of a powerful illuminating apparatus and fog-signal, were commenced in the spring of 1883. The first and lowest stone was set on the north-west side of the tower on the 25th of May, 1883; and before the winter season, fifty-seven stones, including a portion of course ten, had been set. The following year, the difficulties of battling with the waves and effecting tide work had in a great measure been overcome. Thus more frequent landings at the tower, and longer hours of work were practicable. The season closed on the 19th of November, when four hundred and fifty-seven stones, including course twenty-two, had been set. The favourable weather experienced in the fall of the year 1885 made work at the tower possible up to the 9th of December, and that day saw the completion of course fifty-four. The sixty-second course, the height to which the dovetailed casing extended, was completed on the 11th of May, 1886; and the demolition of the lantern, the illuminating apparatus, and the masonry forming the service-room of the granite tower, was immediately proceeded with. Without in any degree interfering with the nightly service of the light to mariners, the central crane was substituted for the gallery course setting crane, the temporary lantern fixed thereto, and the original lantern and dioptric apparatus removed for service elsewhere. At the level of course sixty-two, a timber stage was erected, provided with rails and a truck. Upon the latter, the blocks of stone forming the service-room of the former tower were lowered by means of the traversing jib, after removal from the wall. The truck was then run out, and the stones automatically tipped into deep water clear of the tower and rock. The work of erection was again proceeded with on the 26th June, and the masonry of the remaining four rooms completed by the 30th of August following; and here the rapidity of the operations, as compared with the tediousness of the dove-

tailoring, is worth noticing. Thus the time occupied in the preparation for, and setting of, the additional masonry, amounting to 3,220 tons, was rather under three and a half years. The permanent light was exhibited on the 25th October, 1887, and the work brought to a conclusion in December.

The temporary catoptric illuminating apparatus consisted of an 8-foot Trinity House cylindrical floating-light lantern, in which were placed two groups of 21-inch parabolic silvered reflectors, three in a group. The reflectors were provided with two-wick "Trinity House Douglass" burners, consuming heavy mineral oil. This arrangement admitted of the exhibition of a light similar in distinctive character to the light designed for the new tower, viz., "double flashing" of one minute period. The power of the flash of light issuing from each group of reflectors was equal to sixteen thousand standard candles, thus exceeding the intensity of the old light of fifteen thousand candles, which had previously been improved by substituting a "Trinity House Douglass" burner of six wicks for the original four-wick "Fresnel" burner. On the erection of the permanent lantern, the temporary lantern and illuminating apparatus were removed, and the latter arranged at the upper portion of the permanent lantern.

The present lantern is of the usual Trinity House cylindrical helically framed type, 14 feet in diameter, and 15 feet high in the glazing. The pedestal is of cast-iron, the framing is of gun-metal, and the steel rafters forming the roof are covered with thick copper sheet. The roof has the improved arrangement of the Trinity House for the thorough ventilation of the interior, without subjecting the flame of the burners to any down-draughts. The lantern and optical apparatus were constructed by Messrs. Chance Bros. and Co., of Birmingham. The optical apparatus consists of two superposed tiers of lenses of the greatest focal distance, viz., 1,330 millimetres, hitherto installed in a lighthouse (Plate 6, Fig. 7). Each tier is composed of ten lenses, each subtending a horizontal angle of 36 degrees, and a vertical angle of 80 degrees. Each lens is built up of a centre, and seventeen rings above and seventeen rings below that centre. The duration of flashes and eclipses are as follows:—

	Seconds.
Flash	4½
Eclipse	4½
Flash	4½
Eclipse	46½
Total period	60

In clear weather the lower burner, which is worked at minimum power, transmits through the lower apparatus a light of 40,000 candles to the horizon; but when the atmosphere is impaired for the transmission of light, the two burners are worked at maximum power, thus increasing the aggregate beam transmitted through the double apparatus to 230,000 candle-units. The change from minimum to maximum power is made whenever the light at St. Agnes lighthouse, 5 miles distant, is not clearly visible. For the purpose of securing the utmost efficiency of the flashes of the upper tier of lenses, which are only used during thick weather, these lenses are focussed for utilizing the maximum efficiency of the flame of the burner on the sea at a distance of 5 miles.

In the service-room, two 100-gallon Trinity House improved pressure lamps are placed. These lamps supply the two eight-wick "Trinity House Douglass" burners with heavy mineral oil of 250° Fahrenheit flashing point. The burners are carried on burner changers. The framework of the optical apparatus is necessarily constructed of a heavy section, to withstand the shocks to which it is occasionally subjected by heavy masses of water striking the tower. The power requisite for its rotation is beyond that of the ordinary clockwork actuated by manual power, and thus it became necessary to introduce special machinery for the purpose. This machinery comprises a pair of $1\frac{1}{2}$ effective HP. "Davey" safety motors and air-compressors, working into two vertical steel air-receivers, placed over end at the centre of the tower. Sufficient air is compressed into these by day for working a small air-engine placed in the pedestal of the illuminating apparatus, by which the latter is kept in rotation during the night. A winch worked by compressed air is placed on the lantern gallery, for landing stores and light-keepers. The annual consumption of coke for working the "Davey" motors does not exceed 14 tons. The whole of the machinery is worked by trained light-keepers, without the aid of a skilled mechanic, except for occasional overhaul and repairs.

A gun-cotton explosive fog-signal is attached to the lantern, which takes the place of the fog bell formerly employed. This very efficient type of fog-signal is now in successful operation at five Trinity House rock lighthouse stations, for it was found impracticable to introduce, in the limited space available, special machinery of such power as required to work a siren of the type in use at shore lighthouse stations, and on board light vessels. The apparatus consists of a hollow steel crane attached to the lantern, and actuated by a worm-wheel and pinion. For the attachment of the gun-cotton charges, the crane is lowered, and two

charges are suspended to the firing cables which are connected with a dynamo electric exploder placed within the lantern. After suspending the charges, the crane is raised to its upper position, and contact made at five-minute intervals. A charge consists of 4 oz. of gun-cotton, into which a fulminate of mercury detonator is placed before suspension. Prior to the introduction of this type of fog-signal, a 5-cwt. bell, suspended from the lantern gallery, and actuated by clockwork, was sounded in foggy weather. During the five years the Author was engaged in the reconstruction of the tower, six wrecks took place during thick weather, within a radius of 5 miles of the tower; but since the introduction of the gun-cotton signal, in 1888, the Author is not aware of a single wreck having occurred within this radius during foggy weather.

It is very satisfactory to record that throughout the whole of the dangers incurred in the erection of the three lighthouses at this station, no loss of life or limb has ever occurred.

The cost of the work executed at this station from time to time is as follows :—

	£	s.	d.
1. Cast-iron lighthouse	12,500	0	0
2. Granite lighthouse	34,559	18	9
3. Improved granite lighthouse	64,889	0	0
Total	111,948	18	9

If the usual test of cost for such structures is applied to the Bishop Rock lighthouse as it now stands, namely, per cubic foot of granite masonry, it amounts to £1 8s. 6d., which compares favourably with other sea structures.¹ On the other hand, if the value is estimated from a nautical point of view, at per unit of intensity of light provided, it will be found to be lower in cost than any other first-class sea lighthouse.

The Paper is accompanied by a series of drawings, from which Plates 4, 5, and 6 have been prepared.

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 36.

(*Paper No. 2593.*)

**“The Illumination by Gas of Tory Island Lighthouse,
County Donegal.”**

By DAVID CUNNINGHAM SALMOND, Assoc. M. Inst. C.E.

THE Author proposes to give an account of the various alterations made, during the years 1885–1887, to provide for the adoption of gas as an illuminant at the lighthouse on Tory Island, situated on the north-west coast of Ireland, off county Donegal, which works were carried out by him under the Engineer to the Commissioners of Irish Lights, Mr. William Douglass, M. Inst. C.E. The question of gas as an illuminant for lighthouses had been carefully considered, prior to its adoption, and the results of the experiments and discussions were given in a Parliamentary Blue Book.¹

The lighthouse was first lit in the year 1832, and, at the time of the commencement of the works here recorded, consisted of a six-wick, first-class dioptric, fixed oil-light, which was extinguished 6th April, 1887. The dioptric apparatus consisted of a bee-hive shaped lens of the usual type, with central annular lens, top prisms, and bottom prisms.

In the interval between the extinction of the old light and the establishment of the new, the illumination of the station was maintained by a temporary apparatus, similar in arrangement to those used on lightships; this was secured round a mast at a height sufficient to prevent obscuration by the erection of the new works, the mast being properly needled and guyed to the tower, with ladder communication from the gallery, as shown on Plate 7.

GENERAL DESCRIPTION OF STATION.

Plate 7 shows the lighthouse tower as it stands at present, rising 60 feet from the level of the yard paving to the top of the gallery, and having an internal diameter of 11 feet 9 inches. The walls are 7 feet thick at the first floor, gradually tapering

¹ “Lighthouses. Papers relative to a proposal to substitute gas for oil as an illuminating power.” Folio. London, 1869–75.

upwards to a thickness of about 3 feet 6 inches under the gallery level. The walls are of granite, mostly quarried at the site; and the tower contains five floors, all lighted by windows, and reached by a stone winding stair. The top of the vane is 36 feet above the gallery floor, and the centre of the light is 130 feet above high-water level. Around the tower are situated the station buildings, the keepers' dwelling-houses facing the entrance to the tower, and the various workshops flanking each side, the vacant side being enclosed by a wall 9 feet high. Standing further away are two new dwelling-houses; and enclosed in a yard, apart from all the other buildings, are placed two gas-tanks, the gas house, coal stores, purifying shed, and station-meter house. The siren house also stands by itself, about 70 yards distant, nearer the edge of rocks; in this position it commands the open sea, and the notes given forth by the sirens are not obstructed or diverted in any way. Inside the lantern watch-room is fixed an electrical indicator, with separate communication to four dwelling-houses, the gas house, and siren house, with return bells from each, so that in case of a fog arising at night, the keeper in charge can ring up additional help, at the same time turning on the increased light power.

Ample storage for water for domestic use is provided by concrete tanks, which receive all that can be gathered from the roofs. There is also a spring on the island, almost uninfluenced by the dry season. The remaining portions of the ground are enclosed by high walls, 2 feet thick, with a strong iron entrance gate. The staff consists of a principal keeper, two assistants, and a gas man.

NEW LIGHT.

The new light consists of what is known as a "Wigham" triform gaslight, of the latest improved construction, and, as is implied by its name, is formed by three superincumbent tiers of lenses placed inside the lantern, Plate 7. In the focus of each tier of lenses is placed a 108-jet gas-burner, making, when full on, a total of three hundred and twenty-four burners, equal practically to nine thousand candles; and, taking into consideration this illuminating power, the hyper-radiant long-focus lenses used are capable of making the light from the three burners equal to about seven million candles, according to Mr. Allard's formula. A feature of these burners is that no glass chimneys are required. The full tiers of lenses are made to revolve, thus giving forth a full, concentrated beam every minute, which is again subdivided into flashes. The lenticular apparatus is hexagon on plan, each

side containing twenty-two annular rings on each tier, varying in thickness from $1\frac{7}{8}$ inch to $1\frac{1}{8}$ inch, the bull's-eye being $14\frac{3}{4}$ inches in diameter, and $1\frac{3}{8}$ inch thick at the centre; and each side contains about $85\frac{1}{2}$ square feet. In ordinary fine weather, thirty-two jets in the bottom light are sufficient to reach the horizon; but when a fog comes on, the seventy-six additional jets are lighted in this burner, and at the same moment the other two burners of one hundred and eight jets each are used. The changes from one power to another can be made very quickly by the aid of a peculiar arrangement of mercurial joints.

Groups of flashes are caused by breaking up the full beam from the lens, by continually shutting off and turning on the gas. This is accomplished by a cam fixed on the rotating clockwork, placed under the lens table, from which a connecting-rod rises up through the lantern; and as the cam revolves, the cogs lift and raise the rod, shutting or opening the valves at the same moment. The result of the group flash is that the mariner sees, instead of a long flash of light recurring at certain intervals, a group of shorter flashes; and by this arrangement the lighthouse is identified. This device is a distinguishing and much required feature on a great landfall such as Tory Island.

LANTERN.

After clearing away the old lantern down to the gallery level, and carefully levelling over all the surface of the stone floor left, a cast-iron gallery flooring was laid down in sections, and secured to the stone gallery with $1\frac{1}{4}$ -inch wrought-iron bolts. On this a cast-iron pedestal of $\frac{1}{2}$ -inch metal was built in segments, standing 6 feet high all round, with side flanges about 5 inches deep (one section being for the doorway), and ribs recessed at the top to receive the ends of the lantern standards; and the pedestal sections are bolted together and down to the cast-iron gallery. To the top flange of the pedestal are secured sixteen vertical standards of milled steel, $5\frac{1}{2}$ inches by $1\frac{1}{4}$ inch, fitting tightly into the holes slotted in the top. The bars had to stand a tensile strain of 28 tons per square inch of sectional area, with a contraction of area of 35 per cent. On the top of these standards, a wrought-iron cornice plate, 6 inches by $\frac{5}{8}$ inch, is formed of thirty-two pieces, and joined and jointed with countersunk rivets, a wrought-iron screw being tapped into each of these standards. From this cornice, sixteen wrought-iron T bars spring, 3 inches by 3 inches by $\frac{3}{8}$ inch, shaped at the ends to take a wrought-iron cornice plate and connecting

ring at the top, being secured by $\frac{1}{2}$ -inch bolts. The ring is 3 feet in diameter, 12 inches deep, and $\frac{3}{8}$ inch thick. The roof is covered with copper sheets, 3 lbs. to the foot, fitted in between the T bars, bedded in lead, and secured with $\frac{1}{2}$ -inch brass bolts. The gutter round the lantern is also of copper, 4 lbs. to the foot; the upper edge of the gutter being wired with $\frac{1}{2}$ -inch wrought-iron wire. Gun-metal covering plates were cast to cover the joints, and all bolted together. The down-pipes are of copper, and are carried down in front of the standards. The neck of the lantern is likewise of copper, and overlaps the roof sheeting. On the upper end of this neck was fixed a wrought-iron ring, carrying four arms to steady the spindle, which is also strengthened by two strong wrought-iron cross-bars fixed to the neck.

The cowl on the top is of copper, raised with the hammer, and shaped as shown in Plate 7. On the crown is fixed a case-hardened, steel step, which works on the point of the spindle. The spindle is pointed with steel and bolted to cross arms, and passes through rings at the end of the neck, and gun-metal bushing in the arms of the cowl. The cowl is surmounted by a vane, the shaft being of wrought-iron, the ball of copper, and the feather and barb of strong hammered copper. The standards of the lantern were fitted in with three tiers of wrought-iron astragals, $4\frac{1}{2}$ inches by $2\frac{3}{4}$ inches by $\frac{1}{2}$ inch thick, secured at the ends to standards with $\frac{1}{2}$ -inch bolts. The astragals have a copper strip, $1\frac{3}{8}$ inch broad and $\frac{1}{8}$ inch thick, fitted with four brass studs and nuts tapped into them, the studs forming the rebates for the glass. Down the outer edge of the standards are tapped brass studs with nuts to take glass, and copper cover-strips, $\frac{1}{8}$ inch thick; and to each standard are secured four malleable iron handles, bolted with studs to the standards.

The whole of the lantern is glazed with $\frac{3}{8}$ -inch plate-glass, the edges of the glass touching the brass studs on all sides; the space was packed in with red and white lead putty; and the copper strips were then screwed on, and made watertight. The centre space between the cast-iron gallery boxing is filled in with a circular riveted girder, 12 inches by 5 inches, with arms of the same section riveted with angle bars to the centre one, and also bolted to the inner side of the cast-iron gallery, thus forming a floor for the base of the lenses. The floor of the lantern is fitted in between the girders with cast-iron gratings in sections. On the top of this floor, and bolted to the girders, is built the base of the lenses, formed in sections of cast-iron and glazed; and the clockwork machine is placed inside. On the top of the base are the roller-

path and live-ring, on which the steel lattice girder carrying the lenses sits.

CLOCKWORK MACHINE.

The clockwork for driving the lens table is constructed of gun-metal and brass with ball bearings, and is driven by an endless chain connected with a weight cage running down a recess in the tower wall, and wound up every four hours.

GAS APPARATUS.—RETORT-BENCH.

The retort bench consists of seven cast-iron D-shaped retorts, 14 inches by 15 inches inside, by 7 feet long, and of $1\frac{1}{4}$ -inch metal, set in two single, one double, and one three-tier settings; the retort bench being built with fire-bricks, and tiles built in fire-clay. The mouthpieces of the retorts project 10 inches, and have a faucet cast on to take the ascension pipes. These pipes are of $\frac{3}{4}$ -inch metal, and tapering from 4 to 5 inches diameter, are carried up to the hydraulic main over the bench. The main, of 12-inch bore and $\frac{1}{2}$ -inch metal, is in two parts, standing 18 inches over the bench top, and supported on cast-iron crutches. The ends are closed with flanges secured by bolts and nuts, one end being blank with cleaning doors, and the other end having a socket to receive a 5-inch pipe, which is reduced to 4 inches at the tar tank.

The gas from the hydraulic main passes into a condenser, consisting of a bottom box in one casting, with divisions arranged to pass the gas up and down eight pipes, each pipe being 9 feet long and 4 inches bore. From the bottom of the tank is carried a 2-inch overflow pipe to the tar tank, provided with a seal to prevent the escape of gas. The gas is then passed from the condenser, by a 4-inch pipe, to the vertical scrubber, and passes down through the scrubber. The latter is 8 feet high and 2 feet in diameter, formed of cast-iron, and is provided with a flushing rose and cistern, and tar-pipe outlet to the tank.

The gas passes from the scrubber through two dry-lime purifiers, each 4 feet 4 inches long, 2 feet 5 inches wide, and 2 feet 3 inches deep, with a division plate, each purifier being in two castings, with cast-iron covers provided with air and testing plugs, and five tiers of wooden turned-bar sieves for lime. There is a water seal round the top of the purifiers, 8 inches long by $2\frac{1}{2}$ inches wide. The lids are lifted by means of a 10-cwt. differential pulley-block and chain. Between the purifiers is placed a change valve,

arranged so as to pass the gas through either or both of the boxes, or past them direct, by the 4-inch main, to the station-meter, which is capable of passing 1,000 cubic feet per hour. Between the purifiers and the meter, a second by-pass valve is placed, so that in case of any breakdown of the meter, the gas can pass on to the gasholder. This expedient is adopted throughout, so that all direct parts of the apparatus are in duplicate. The gas passes from the meter on to the valve house, where there is an arrangement of valves and by-passes by which it can reach either gasholder. The gas passes by a 4-inch pipe from the valve house into the tank, and down into the cast-iron tank siphon, 3 feet 6 inches long, 1 foot 8 inches wide, and 10 inches deep, made in one casting of $\frac{1}{2}$ -inch metal, with a division plate; it thence proceeds to the gasholder, and leaving the latter, passes back down a pipe into the box, and so reaches the valve house. The siphon box has a $\frac{3}{4}$ -inch gun-barrel pipe passing down its inlet pipe, with connections at the top where a small pump can be attached for cleaning the box.

GASHOLDERS.

The gasholders are well-constructed vessels, 25 feet in diameter by 10 feet deep, with two curb rings, $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches by $\frac{1}{4}$ inch, the bottom curb being placed outside. There are four principal rafters of flat iron on edge, $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch; four secondary rafters of flat iron, $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch, and purlin bars, $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch, on edge; tension rods, each $\frac{7}{8}$ inch diameter, attached to the principal rafters; and a centre truss cap, which is of cast-iron. The crown plates are 2 feet 6 inches in diameter, $\frac{1}{4}$ inch thick, with two circles of No. 14 B.W.G.; the outer circle is of No. 13 B.W.G., and all the side sheets are of No. 14 B.W.G., except those of the top course, which are of No. 13 B.W.G., and the sheets of the bottom course, which are of No. 12 B.W.G. Four top guide-rollers are fixed to work against 2 inches by 2 inches by $1\frac{1}{4}$ inch T bar guides secured to the columns, with four guide-rollers at the bottom to work on the wrought-iron guide built in the masonry walls of the tanks. The rise of the roof of the gasholders is 1 foot 9 inches. The framing for bearing the tanks consists of four cast-iron columns, 12 inches in diameter, 9 feet high, with cap and base moulding, bolted down to piers in the wall of the tanks. On the top of each column is a sheer, 3 feet 6 inches high, to receive the chain wheels, 3 feet in diameter. The columns are attached at the top by lattice girders, 18 inches deep, with top and bottom flanges

of angle bars, $1\frac{1}{2}$ inch by $1\frac{1}{2}$ inch by $\frac{1}{4}$ inch, the lattice bars being of iron, $1\frac{1}{2}$ inch by $\frac{1}{4}$ inch.

SIREN HOUSE.

The siren installation consists of two 8-HP. Otto gas-engines resting on concrete-block foundations. Facing these engines are placed two air-compressors, driven by belting, and capable of utilizing the full power of the gas-engines. The air-compressors communicate with two air reservoirs, 7 feet high, 4 feet 6 inches in diameter, and each fitted with a manhole door. These air reservoirs are supported on wrought-iron legs, and each is capable of sustaining a pressure of 100 lbs. to the square inch. In the centre of the room is fixed a siren stand or support for the trumpets, standing 6 feet high, 6 feet 6 inches by 5 feet 6 inches at the base, and 5 feet by 4 feet at the top, constructed of wrought angle bars, 3 inches by 3 inches by $1\frac{1}{2}$ inch, well braced, and bolted to the concrete floor. All the connections between air-compressors, air receivers, and sirens, are made of the best wrought-iron tubing, capable of bearing a pressure of 100 lbs., with $2\frac{1}{2}$ inches gun-metal screw-down stop-valves. On each receiver is fixed a safety-valve to blow off at 40 lbs. per square inch, and a pressure gauge to record to 80 lbs. per square inch. A wrought-iron water-tank is provided at each end, capable of holding 750 gallons for the use of the gas-engines. A gas regulator and gas bag for the engines are also provided. In the roof framing are fixed wrought-iron guide rings, with wheels for guiding the trumpets when they are being turned to face with the wind.

On the top of the siren stand are placed two sirens, making 1,200 revolutions per minute, with trumpets rising through the roofs. Thus every portion of the machinery is in duplicate, in case of a breakdown occurring in such an isolated position where communication with the mainland is not always certain. The best cannel coal is used for the production of the gas, which is usually landed during the summer months at the north landing, where a crane has been erected.

OIL LAMPS.

In case of breakdown of the gas apparatus, an ingenious arrangement is provided, whereby in a few seconds a six-wick oil-light can be substituted for the bottom gas one, a cistern for oil being

arranged behind the flue space. The oil-light can be shut off by an arrangement of clappers, which are made to open and shut round the light, and are worked by a lever off the same clockwork that revolves the lens table, so that the group flashing arrangement is retained.

The building contract was carried out by Messrs. Colhoun Brothers, of Londonderry, Ireland. The lantern and gas apparatus were supplied by Messrs. Edmundson and Company, Capel Street, Dublin, the lens being manufactured by Barbier, of Paris.

The Author has to accord his best thanks to the engineer, Mr. William Douglass, and the patentee of the gas apparatus, Mr. John R. Wigham, for their kindness in permitting him to describe this work, and for valuable information given.

The communication is accompanied by eight tracings, from which Plate 7 has been compiled.

[DISCUSSION.]

Discussion.

Mr. W. T. DOUGLASS explained that the apparatus of the gun-cotton explosive fog-signal used at the Bishop Rock consisted of a hollow balanced steel crane, working on a joint attached to the lantern roof, and capable of being raised or lowered by means of a worm and worm-wheel, actuated by a handle attached to the lantern pedestal. The electric cable was carried at the back of the crane and led to the dynamo electric firing machine placed within the lantern. When the signal was required, the crane was lowered, and two 4 oz. charges of gun-cotton, with detonators enclosed in waterproof envelopes, were attached to the cables. The crane was then raised, and the charges exploded, at intervals of five minutes, by the dynamo. A safety lever, in connection with the crane, prevented the possibility of the gun-cotton charges being fired before the crane was raised to its firing position, by automatically withdrawing the cables from the dynamo, and thus breaking contact.

Mr. Douglass.

Sir JAMES N. DOUGLASS said he had had a very long acquaintance with the "Bishop." He was with his father, as chief assistant, throughout the erection of the iron lighthouse, and for two years on the second work, when he was succeeded by his brother. During the erection of the first lighthouse, the depôt was on Rosevear, a small island about 2 acres in area, and rather more than 1½ mile from the "Bishop," eastward and landward; and on that island they had excellent opportunities of watching what was going on at the "Bishop" during storms, from the top of a cairn about 40 feet above high water. During the progress of the work, they found that the seas were very little arrested by the iron columns, and it was hoped that they would never reach the closed superstructure; but directly they did so, it was carried away. After the completion of the second work, they had more detailed information, through the light-keepers, as to the exact movements of those heavy seas, which were admirably shown on the diagram, for the accuracy of which he could himself vouch. The primary wave flowed freely over the rock, at a height of about 50 feet above its summit. There was very little break in the wave, except on the tower itself; and there a rather lighter wave rose and reached the cavetto of the lantern gallery, where a third, and still lighter wave was produced of heavy spray, which

Sir James N. Douglass.

Sir James N.
Douglass.

struck the lantern, and rising far above it, was driven a long way to leeward, sometimes nearly a third of a mile during a heavy storm. He had visited many parts of the world, east and west, but had never seen heavier seas than he had witnessed at the Bishop Rock, where everything appeared to be favourable to their development. The failure of the first lighthouse might, to some extent, be considered fortunate, because it furnished information that up to that time they had no idea of; it also gave them experience for the second lighthouse, the completion of which encouraged the Corporation of Trinity House to proceed with other sea structures at home and abroad. It likewise led to the development of the present lighthouse, which was very different from anything they had thought of at first, and which had become now a positive necessity for navigation. A flashing light was at first suggested; but it was not deemed prudent to place it in the lighthouse, on account of its fragile nature, and the necessity for clockwork to drive it. With the heavy vibrations occurring in the second tower, there would have been very great risk of having the light frequently stopped; and an apparatus for a fixed light of less power was therefore adopted. It was now found that a "Fresnel" apparatus in such a structure must be far stronger and heavier than in a shore lighthouse. With increased strength, increased power would be required for rotating it. The weight of the present optical apparatus on the horizontal rollers was $8\frac{1}{2}$ tons; and the ordinary weight of a first-order dioptric apparatus was about one-third of this. It was beyond the power of a light-keeper to wind up the necessary clockwork for this, which had to be done during his watch, in addition to the other duties which he had to attend to. The motive power accordingly required, had been very efficiently provided by the small "Davey" safety motors in the small space at disposal in connection with the air-compressors, and the very small compressed-air engine placed in the pedestal of the illuminating apparatus. The explosive gun-cotton signal was first introduced at the Smalls Rock lighthouse in the Bristol Channel in 1878, and it had been found to be a very efficient substitute for the first-class siren in positions where there was not enough space for the necessary machinery. The honour of having rendered aid and advice to the Corporation of Trinity House in the development of that signal, was due to their honorary member, Sir Frederick Abel. The optical apparatus for gas described in Mr. Salmond's Paper, was of the same dimensions as that at the "Bishop," namely, 1,330 millimetres focal distance; but it had three tiers of burners and lenses, instead of two as at the "Bishop,"

where it would not have been prudent to have risked an apparatus of greater height. The system adopted at Tory Island of producing a group flashing light had two serious defects, especially for a coast light where two or three lights of the same description were required in the same neighbourhood, first, the uncertainty in the number of flashes in each group, and secondly, the want of uniformity in the intensity of the flashes. At the "Bishop," the system of Dr. John Hopkinson had been adopted, as was usual with all similar apparatus of the Corporation of Trinity House. With these apparatus, the number of flashes in each group was identical, because a separate lens was devoted to each, as shown; and the flashes from each were also always identical in their intensity. It had been stated by Mr. Salmond that the aggregate intensity of the three 108-jet burners was 9,000 candles, and the aggregate intensity of the flashes from the lenses 7,000,000 candles, according to the formulas of Mr. Allard. As he (Sir James Douglass) could not agree with those figures, and as the question was one of importance to members of the Institution and to mariners generally, he thought that it was his duty to set right what he regarded as a palpable error. At the well-known investigation, made by Trinity House at the South Foreland in 1884-5, into the relative merits of electricity, oil, and gas, photometric measures were made by Professor Harold Dixon, F.R.S., at distances of from half a mile to a mile, which had never previously been done. The measurements were made of the flashes from large lenses and gas-burners; and the results were found in all cases to be inferior to the Tables published by Mr. Allard, the reason being that these Tables were prepared for the more highly condensed flames of oil burners. In estimating the intensity of the flashes emitted from the "Bishop," the practical measurements of Professor Harold Dixon had been adopted as their data; and if the flashes from the Tory Island apparatus were estimated on those data, the intensity would be about 360,000 candles, and not 7,000,000 as stated by Mr. Salmond. The siren fog-signal described in Mr. Salmond's Paper, was of the Trinity House type, and was sounded at a pressure of 40 lbs. to the inch. He had lately found that in adopting a pressure of about 20 lbs. with a properly constructed siren, he obtained about double the efficiency. They were gradually gaining experience in the economical use of compressed air, and he thought it was very important that it should be adopted for sirens where it could be used at a low pressure. It would have added much to the interest of the Paper if the Author had stated the cost of the work. The development of

Sir James N.
Douglass.

Sir James N. Douglass. coast lights and fog-signals by mineral oil, gas, and electricity, was a subject well worthy of consideration by the members of the Institution; their exact present knowledge respecting it should therefore be fully realized. It was now known that a first-class coast light and fog-signal of the highest powers attainable, with mineral oil or gas, was of about equal efficiency; but there was this difference, that the first cost and maintenance was fully 20 per cent. more for gas than for mineral oil. For an important landfall station, such as Tory Island, a steam-power electric light and fog-signal, of about ten times the power of that on Tory Island, could be produced at only 60 per cent. more cost than with mineral oil. They had such enormous power at their disposal with the electric arc light, that only one radiant and one tier of lenses were required when electricity was used; whereas, with oil at the "Bishop," two radiants and two tiers of lenses were adopted; and at Tory Island, with gas, there were three radiants and three tiers of lenses. It should further be remembered that coast lights and fog-signals with steam and electricity, having about ten times the power he had referred to, were now available, the power being limited by cost only.

Mr. Abernethy. Mr. ABERNETHY, Past President, said he was sure he expressed the general feeling of the members in returning their thanks to the Author for his admirably illustrated Paper on a very interesting and important subject affecting the safety of a vast number of ships, increasing in size and in speed, frequenting the British coasts, and in many cases navigating very intricate and dangerous channels. He could appreciate the vast progress made in lighthouse engineering from the fact that fifty years ago he was a young assistant at the erection of the Start Point lighthouse, and had subsequently, more than forty years ago, been engaged in connection with various lights on the east coast of Scotland. Great progress had been made in the construction of the buildings themselves. Start Point lighthouse, he believed, was a very good specimen of work; but it was erected upon a headland above the reach of the sea, and not subject to the great contingencies that had been so well overcome by Sir James Douglass and his able assistants. One important improvement, lately effected by Sir James Douglass, was the adoption of a vertical wall at the base of the lighthouse to receive the first impact of the waves, and to resist and break their shock. No doubt the waves would still rise up the tower of the lighthouse, but their volume would be very much diminished. Although the British coasts were admirably provided with salient lighthouses at all points, nevertheless there

was a paucity of local and subordinate lights. More than forty years ago there was an admirable lighthouse at the port of Aberdeen, the Girdleness, situated on a peninsula $\frac{1}{4}$ mile eastward of the harbour. It was a first-order light, but the harbour having a narrow and a dangerous entrance, numerous wrecks took place; and though a single light was erected on the end of the North Pier, it was an ineffective guide to entering such a harbour where there were littoral currents outside, because in steering it was impossible to judge how far the ship was to port or starboard of the centre of the channel. Many wrecks took place, sometimes within the harbour, sometimes at the end of the North Pier, and sometimes to the north of it. Leading lights were finally erected, and very few accidents had taken place for a number of years. Similar lights had been constructed at numerous fishing harbours upon the east coast of Scotland, following the example of Aberdeen; and he had been much struck, in a voyage that he had lately made round the whole coast of Ireland, to find that on the Atlantic side, frequented by a vast number of a superior class of fishing boats, and where excellent harbours existed, but with dangerous entrances, no precaution had been taken to construct leading lights; so that in a dark stormy night, and thick weather, it was difficult for the fishermen to find the entrance, and no doubt many boats had been lost in consequence. If electric communication could be established between lighthouses and the nearest port, or life-boat station, it would be an enormous benefit, and would prevent a great loss of shipping and life. That was a most important question, and deserving of consideration by the legislature.

Mr. W. H. PREECE said he did not propose to take the opportunity of drawing a comparison between the relative merits of gas and electricity for lighthouse purposes, but would simply take up a point alluded to by Sir James Douglass. He thought there must be a clerical error in attributing 7,000,000 candle-power to 1,000 cubic feet of gas burnt per hour, for this amount, if consumed directly with oxygen, would give a power of 9,000 candles; but if that same 1,000 cubic feet of gas were consumed in the breach of a gas-engine, it would give in the electrical arc no less than 60,000 candles. If 1,000 cubic feet of gas when used as on Tory Island, would only give 9,000 candles, and when used as at the Lizard and other places gave 60,000 candles, he did not think there was much necessity for his drawing any comparison between the relative merits of the two. An interesting question had been referred to by Mr. Abernethy, namely, communication between the lighthouse and the nearest port, and between the

Mr. Abernethy.

Mr. Preece.

Mr. Preece. lightship and the shore; and a more important point still was the possibility of communicating from lighthouse to ship through what was absolutely an obstructive, namely, fog. First, between light-house and shore, or between lightship and shore. There was on the table a model of the method applied at the Sunk lightship to maintain communication with the shore, which it did for three years; but it was abandoned for reasons that it was then useless to refer to. As Mr. Abernethy had said, it had been suggested that it was the duty of the legislature to take up the question, and that all lightships and all outlying lighthouses should be connected with the shore. To do so by submarine cables would be a very costly undertaking. At the same time, it was a question that was now under consideration; and as it would probably be referred to a Committee of the House of Commons, or both Houses, it would be unbecoming in him to say much on the matter. He wished, however, to point out that it was not absolutely necessary to connect a lightship or a lighthouse with the shore by means of a submarine cable, but that it was within the bounds of possibility to communicate through great distances without any connecting wire whatever. He brought the matter before the British Association at its Manchester meeting in 1887; and about two years previously his attention had been called to the fact that some wires which were carried on poles, down the Gray's Inn Road, on the tops of the houses, were subject to certain disturbances from wires that passed underneath the road at a distance of 80 feet. On careful examination it was found that messages which were transmitted through the wires underground, were actually readable upon the wires 80 feet above ground. That led him to experiment, and he was rather overcome at the time with the novelty and interest of the question. He thought he had discovered that it was possible to read on one side of England signals that were transmitted upon the other side of England. Signals were sent between Newcastle and Berwick, and he distinctly read those signals at Gretna Green, on the other side; but he had reason to believe afterwards that they were not absolutely conducted through the ether, but that probably they were assisted by the system of railways between the two places. He afterwards, however, conducted some very careful experiments indeed down the two banks of the Severn, from near Gloucester to Berkeley on the one side, and between Lydney and another place on the other side; and there, although the distances apart were more than a mile, and with no possible connection of any kind between the two places by intermediate wires, they succeeded in getting signals on one side of the Severn,

which were transmitted to the other. Moreover, the same kind of Mr. Preece. signals were transmitted between two new lines of telegraph in the neighbourhood of Worcester and Shrewsbury; and there he was able, by careful experiments, to determine the law that regulated the distance to which those signals could be communicated. After reading his Paper in 1887 he allowed the matter to drop; but now that this important question was coming to the front he was, with, he hoped, the assistance of Sir James Douglass and the Trinity House, and the assistance of the War Department, about to try a series of experiments to see if there was any truth in the experimental results he had previously obtained which had led him to assert that they would be able to communicate between lightship and shore without a connecting wire of any kind. The next point was the possibility of communication between lighthouse and ship through a fog that was absolutely obstructive to light, and also to a certain extent to sound. The whole tendency of the inquiries into electricity at the present time was to show that electrical phenomena were precisely of the same class as the phenomena of light. Electrical disturbances were transmitted through space in undulations of exactly the same kind as those undulations which, when impinging upon the retina of the eye, gave the effect called light. There was very little difference in character between those disturbances of the atmosphere that produced what was called sound, and the undulations that produced light, except that light was due to the motion of the ether, and sound was due to the motion of the air. There was, however, this great difference that, while the undulations of the air producing sound were of very slow frequency, varying between, perhaps, one hundred vibrations per second up to two or three thousand, light resulted from vibrations amounting to thousands of millions per second. Between the two there were certain vibrations which were easily calculable, and which took up an intermediate stage. He had little doubt that if they were to experiment in that direction, it would be found that those vibrations, which might probably be something like a million or two millions a second, would pass through fogs, which probably would not be the case with the higher vibrations like those of red light. He wished to point out that they had something to experiment upon, for there was something which certainly did transmit through fogs—something which, if they had the sense, would enable them, not to hear or to see, but to feel in some way or other. That sense had been given to them within the last few

Mr. Preece. years in the shape of the telephone, which really amounted to an eighth sense. It was only last Saturday that he and nine other gentlemen sat round a small table in the General Post Office with telephones to their ears in connection with Paris, and with the Opera; and for three or four hours they sat silent round the table, and heard every sound from the Opera House. There was not a single wrong note in the orchestra, there was not a single scream of the soprano, there was not a single howl of the double bass that was not brought to them with painful accuracy. More than that, one day not long ago, the Salvation band of London was passing in procession by the Royal Exchange, and as it passed their Stock Exchange Office it struck up the Marseillaise. The clerks in the office threw up the windows and exposed the transmitter in connection with Paris. They asked the Paris man to listen and say what he heard; and he replied, "That he heard a band playing the Marseillaise beautifully." He (Mr. Preece) maintained that if by the aid of that eighth sense, the telephone, and with the assistance science at the present day had given them, they were able to transmit those delicate and minute vibrations between London and Paris, separated by a distance of 303 miles, surely they ought not to hesitate to attempt to transmit vibrations between a lighthouse and a ship which might be sailing in darkness within perhaps a mile of the spot. Experiments were wanted, and he thought with a little exertion on the part of some of the powers that be, men and the apparatus would be found; and then the time might come when, instead of Sir James Douglass and his son writing papers on the lighthouse at Bishop Rock, a grandson, or a great-grandson, might come forward and say how communication was held between lighthouse and shore and between lighthouse and ship, not by the lighthouse, but by the electric house.

Mr. Beazeley. Mr. M. BEAZELEY said that, having worked for several years under Sir James Douglass in the Land's End district, on similar works to the one described in the Paper, he desired to congratulate Mr. Douglass upon the successful completion of so magnificent an enterprise, and also on the extremely instructive Paper to which they had all listened with so much interest and profit. He desired likewise to congratulate him on the fortunate combination of circumstances which had enabled the grandson to complete the work of his grandfather, built so many years ago. He did not think that the difficulties connected with any rock lighthouse round the coast of Great Britain could compare with those which had been overcome in the work of strengthening

and raising the Bishop Rock lighthouse. There were round the Mr. Beazeley. coasts about ten rock lighthouses; and there were two celebrated instances in more northern latitudes, one on the east coast and one on the west. But whatever difficulties might have existed in those celebrated works, judging from his own experience, he did not think that they could compare with those surrounding the completion of the Bishop Rock lighthouse. It was a very different matter to set to and build a new structure from undertaking the work of casing a lighthouse, raising it, and having to keep the light going the whole of the time. Then, again, the labour and patience expended on dovetailing away the lower courses to receive the outer casing must have been something enormous. The rock was so small in itself that there was absolutely not sufficient room for workmen to stand on. At dead low water there was a certain length, but very little width; and, consequently, the whole of the work must have been done by cradling. Those who had had anything to do with cradling on such structures would know what an extremely slow and difficult process it was. Moreover, the rock being so small, there was no room to construct a landing-place. At the Wolf and the Longships they were able to construct good landing-places, and thus to land the materials at leisure, and afterwards use them up as occasion required. He observed in Plate 5, Fig. 5, the iron main-mast and top-mast that went through the whole of the Wolf from high water upwards, and went through the construction of the Longships. The landing of that very heavy wrought-iron mast, 30 feet long, and putting it in position in the centre of the tower must itself have been a work of extreme difficulty. Then the maintenance of the light under such circumstances must also have occasioned another great difficulty, because the original light was kept going till the mast was put in. He should like to know how the removal of the old light, and getting the new light to work, were effected. With regard to Mr. Douglass's diagram of the waves, he had gathered from Sir James Douglass that he had estimated the crest of the waves as 50 feet above the top of the rock, which was about high-water mark. That would give a height of 100 feet from the crest to the trough, which was a great deal higher than anything that had been observed at the Wolf. When they had completed the Wolf, and installed light-keepers, he had orders from Sir James Douglass to observe the height of the largest wave. The highest wave that was seen while he was in the Land's End district was 32 feet above the level of the sea, which gave a height of wave of 64 feet from the crest to the trough. Even 64 feet was an enormous height, but

Mr. Beazeley. 100 feet was almost appalling to think of. He admired very much the way in which the men were taken off from the boat and returned to it. He confessed he had read that account with something like envy; and he could not help wishing that they had had, at the Wolf and the Longships, some similar method of landing and of embarking. On many occasions their only resource was, when the sea suddenly got up, to adopt the rough-and-ready mode of being dragged through the surf and hauled into the boat like drowned rats. No doubt Sir James Douglass would remember the memorable Christmas Day of 1869, when he landed a working party to put light-keepers in the Wolf for the exhibition of the light, which had been advertised for the 1st of January. Before the gear could be stowed away, the sea got up so much that the whole party had to be hauled off through the surf into the boat. An anecdote connected with the late Mr. Nicholas Douglass illustrated very forcibly the determined pluck and perseverance and self-relying ability which he exhibited in carrying out his work. The foundation stone of the "Bishop" was below low-water spring-tides, and the rock in the Atlantic received the full benefit of any roll that might come on in that very uncertain sea. The difficulty of getting the stone in was so great that the rest of the work had to proceed as best it could; and the stone had to be left out to wait for a favourable opportunity. He believed that very nearly three years elapsed before the stone was got in. The officials, who came down occasionally to inspect the work, lost patience with it, and one said to Mr. Douglass, "I do not suppose you ever expect to live to get that stone in." Mr. Douglass was by no means a young man, but he said in answer to his questioner, "I do, and remember that I have a father still alive." The stone was got in, and Mr. Douglass's predictions were verified. This was a very forcible illustration of the undaunted bull-dog courage and ability exhibited in carrying out great undertakings, which had made English engineers, and the great works they had accomplished, so celebrated throughout the world.

Mr. Davey. Mr. H. DAVEY said that the little he had had to do with the Bishop Rock was in connection with some of the mechanical contrivances for revolving the light; but he thought the members would be more impressed with the difficulty of carrying out the work of the lighthouse, if they had had even his own little experience in visiting the Bishop Rock. If they were at Penzance on a "dirty" day, and were taken on the "Alert," then put into a boat, and from the boat taken to the lighthouse, and afterwards brought safely back, they would be fully impressed with the

enormous difficulty of the work, and the great perseverance Mr. Davey. needed in carrying it out. The machinery for revolving the light was a very small matter in itself, but presented some considerable difficulties, the main one being a want of space. The space available for engines and boilers was exceedingly limited; and it was necessary that whatever steam was used should be perfectly safe in the hands of men who were not trained mechanics. The motor used had been often described in the technical journals.¹ It was nothing more nor less than a simple low-pressure steam-engine, working with steam below atmospheric pressure; and the only interesting peculiarity about its application which had not been fully described was the provision of the necessary water for effecting the condensation of the steam. Surrounding the base of the lantern was an annular tank, forming a parapet, with tubes coming up to the centre for the circulation of air to give additional cooling surface. The rain-water from the roof of the lantern was conducted into the tank; and there were two pipes leading from the tank, one to the base of the surface-condenser of the small motor, and another return pipe from the top of the condenser to the tank, so that there was a constant circulation of cold water through the surface-condenser, precisely in the same way as in the hot-water systems of greenhouses. The waste of water from the tank was therefore exceedingly small; and he believed that the rain-water from the lantern was sufficient to make up for the waste. There was no other peculiarity in the arrangement beyond the fact that the air-pumps were constructed to pump both to low and high pressure, and were provided with very large pumps, so that at the low pressure they absorbed nearly the full power of the engine. But there was a mechanical device provided by which the resistance of the pump could be lessened as the pressure was increased, so that the single pump was adapted to pumping both high and low pressures. That was almost absolutely necessary because of the exceedingly small space available for the machinery. It would be almost impossible to put in two systems of pumps, indeed there was scarcely room enough for one.

Sir BENJAMIN BAKER, Vice-President, said that a Paper upon Sir Benjamin Baker. lighthouses naturally attracted much attention in Great George Street, because Englishmen were islanders, and it was very difficult for them to get more than 100 miles from a lighthouse. English engineers were also specially familiar with lighthouses on

¹ Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 272.

Sir Benjamin
Baker.

account of the numerous journeys abroad which they had to undertake in pursuit of their professional duties. It must have struck the members, especially when they saw the breezy diagram of the Bishop Rock lighthouse, that it was absolutely essential in such a case to adhere to the general principle which was followed in all marine works subject to heavy seas, namely, that the size and weight of the monolith should be in proportion to the exposure of the situation. In the present instance, the engineers had taken great care, by costly dovetailing and dowelling, to make the whole lighthouse into a monolith. He supposed the weight was about 3,000 or 4,000 tons. [Sir James Douglass: About 6,000 tons.] That was a big lump for the sea to move, even such a sea as that depicted. The cost, £1 8s. per cubic foot, showed that the expense of making the monolith in granite was, ton for ton, very much the same as the normal cost of a cast-iron structure. Indeed, a lighthouse on shore could be built of solid pig-iron throughout, without any of the chambers, for the same price as the Bishop Rock lighthouse, in its exposed situation, cost in granite, with a very good profit realized on the contract. That would give an idea of what an immense proportion of the total cost must have been due to the labour and contingencies consequent upon the exposure of the position. Reference had been very properly made to the personal courage and endurance of the staff who carried out the work; but an attribute characteristic of engineers generally, was courage in carrying out their duties under circumstances of great, and often fatal peril, and that not alone by sea, but in climates where the peril was equally deadly, though not so apparent. He might instance the case of the rebuilding of the Varrugas viaduct last year, where, he believed, nine out of seventeen of the staff died, although the work only took six months. The engineer in charge, Mr. Fraser, in order to save the life of one of the foremen, submitted, with all those terrible surroundings, to the transfusion of blood from himself to the workman. He thought, if they looked into their records, they would find that the members of the Institution, as a rule, did their duty, not only under circumstances of peril, such as those described in the Paper, but under more depressing conditions, when they were very much less under the eyes of their colleagues than Mr. Douglass was, and less likely to receive the recognition due to their services.

Mr. W. T. DOUGLASS, in reply to the discussion, remarked, in answer to Mr. Beazeley, that the light had been maintained, during the removal of the old lantern, by erecting a lightship lantern in

the service-room of the old granite tower, and lifting it by hydraulic jacks, together with the iron mast to which it was attached, to the position occupied by the dioptric apparatus. The former lantern was then removed at leisure. With regard to the height of the waves, as shown in the frontispiece, he had observed the solid waves impelled to the height indicated, from the upper windows of the tower. The "sugar-loaf" formation of the rock materially assisted the rising of the heavy seas which were to be met with at the "Bishop." The height of the waves passing the tower without striking it, did not exceed the height of the vertical base. With regard to the water which was driven over the lantern roof, he had frequently seen the moon totally obscured when observing heavy seas from the interior of the lantern; and doubtless Mr. Beazeley had been an eye-witness of this when engaged at the Wolf Rock lighthouse. Every care was taken to avoid leakage in the condensing tanks referred to by Mr. Davey, as it was very expensive to land water at the tower. The make-up water was obtained from the lantern roof, and this was found sufficient for the purpose. During the winter months, when the engines were more fully employed, the rainfall was greater.

Mr. D. C. SALMOND, in reply to the discussion, said that the aggregate power of seven million candles was based on the following considerations:—Mr. Reynard (Mr. Allard's colleague) had given in his "*Memoire sur l'Éclairage des Côtes de France*," 218·1 as the multiple indicating the power of the ordinary annular lens of his day, 2 feet 7 inches by 3 feet 3½ inches, which was the only annular lens known to, or used by, lighthouse authorities until very recent times. Now the hyper-radiant lenses used at Tory Island were 5 feet 3 inches by 5 feet 8½ inches, and afforded 3·5381 times more illuminating surface than the former; and taking the power of the full gas-light from the three hundred and twenty-four burners at nine thousand candles, and multiplying by 218·1, and the product by 3·5381, the result was six million nine hundred and forty-four thousand nine hundred and thirty-six candles, or, in round numbers, seven million candles, as stated by him. He would refrain from touching on the point raised on behalf of electric light as an illuminant, and from entering into any controversial matter. The cost of the undermentioned works was as follows:—

Mr. Salmond.	Hyper-radiant lenticular apparatus	3,996 ²
	Lantern	1,563
	Siren and engines	1,691
	Building contract, exclusive of roads	8,640
Total		<u>£10,890</u>

Correspondence.

Mr. Stevenson. Mr. CHARLES A. STEVENSON stated that there were several points of dissimilarity between the "Bishop" and other rock lighthouses. He thought that it was very bold to erect a tower of such a large diameter on such a narrow rock, and it was to be hoped that the rock was more than ordinarily sound. Great skill had been displayed, and great trouble and expense must have been incurred in working the new tower in with the old. The system of dovetailing seemed to have been carried out in the most perfect manner; and the method of carrying the floor stones in from the outside of the tower, which was first designed by Mr. Robert Stevenson for the floors of the Bell Rock (now the oldest British rock lighthouse in existence), had been adopted in the new stone floors of the "Bishop," but in this case strengthened by ironwork. The new apparatus was composed of hyper-radiant lenses of 1,330 millimetres focal distance, which were originally designed by Messrs. Stevenson to suit burners of large diameters. The first of these lenses was made for the Commissioners of Northern Lighthouses by Messrs. Barbier in 1885. In designing the arrangement of these lenses for the "Bishop" a stronger light would have been given if the apparatus had been composed of eight lenses in place of ten, or in the ratio 4 to 5, or nearly one-fourth stronger, the apparatus being made to revolve proportionally faster. The 1,330-millimetre lenses for the Fair Isle lighthouse had been so arranged, and were a two-group flash light. Messrs. Stevenson designed an even larger hyper-radiant apparatus in 1883, but as yet none had been made. The focal compactness, or avoidance of divergence by using these large lenses and burners, was very marked. The hyper-radiant lenses used in the South Foreland experiments showed its superiority over smaller lenses; and lighthouse authorities in this country and abroad seem to have realized this, judging from the number which had been ordered.

Mr. L. F. VERNON-HARCOURT observed that the force of the sea, and height of the waves at the Bishop Rock afforded an additional proof that the exposure of any site depended upon the length of fetch, and the depth of the sea in the neighbourhood, in which respects the Bishop Rock was as much exposed as any part of the British coasts. The effect of waves striking against the new lighthouse had not been alluded to, but probably the cylindrical base proved very advantageous, as in the case of the new Eddystone lighthouse, in diverting the waves from running up the tower, as well as in affording a stronger structure at the most exposed part, and a wider foundation for the tower to start from at a higher level. The comparatively large proportionate cost of the work, exceeding by over one-half the cost per cubic foot of the new Eddystone lighthouse, must be attributed to the peculiar difficulties of building round the old structure, fastening the new work to the old, and maintaining the light during construction, which rendered this new lighthouse a unique example of lighthouse reconstruction.

It was unfortunate that the available area of the rock did not admit of the erection of machinery for working a siren, which had been provided on the low outlying rock on which the Ar-men lighthouse was erected in the Bay of Biscay; for fog-signals, serving to warn vessels by day as well as by night, had acquired increased importance now that rapid passages of fast Atlantic steamers were deemed imperative. The recent wreck of the "Eider" on the Atherfield Rocks, only 3 miles distant from St. Catherine's lighthouse exhibiting the most powerful electric light in the world, as well as previous wrecks in the same neighbourhood, demonstrated that distinctive fog-signals formed indispensable adjuncts to the lighthouses round our coasts, to make up for the deficiency in penetration of the strongest lights during fogs. The most powerful siren trumpets appeared to have a maximum range of 6 miles in still weather; but a sonorous signal with this range would be extremely valuable in a dense fog. Perhaps Mr. Douglass could furnish some particulars as to the distance at which the explosion of the gun-cotton charges in use at the Bishop Rock lighthouse and elsewhere, could be heard under normal conditions; for, if the explosion was audible 3 or 4 miles off, this system of fog-signals should be more generally employed. Any information also as to the range of the siren at Tory Island lighthouse would be valuable, as he was convinced that sonorous signals should be far more extensively adopted, as furnishing much more efficient warnings in foggy weather than the most powerful lights.

dr. Wigham.

Mr. JOHN R. WIGHAM stated that the use of gas-engines for driving the fog sirens at Tory Island, referred to by Mr. Salmond, had proved a very great success, as also at other places, chiefly because they could be put into full work at a moment's notice; in that respect contrasting favourably with hot-air engines or steam-engines. He also considered that the Trinity House had done well to attach a gun-cotton explosive fog-signal to the lantern at the Bishop Rock. The details of this rocket were not given in Mr. Douglass's Paper; but, in his opinion, it was very important to attend to the light given by the rocket as well as to its sound. He had known the sudden exhibition of light, high in the air, to arrest the attention of a mariner, when the sound of the explosion did not reach his ear. Hence it was important that the light, as well as the sound of these signals, should be of the highest possible standard of efficiency.

1 March, 1892.

SIR B. BAKER, K.C.M.G., Vice-President,
in the Chair.

It was announced that the following Associate Members had been transferred to the class of

Members.

AUGUSTO TEIXEIRA COIMBRA.
JAMES STRANACH GASKELL.
JOEL LEAN.
WILLIAM PERCIVAL OAK.

WILLIAM WEAVER.
CHARLES PALMER WHITCOMBE.
GEORGE WHITEHOUSE.

And that the following Candidates had been admitted as—

Students.

WILLIAM ALEXANDER.
JÖRGEN BJÖRNSTAD.
GEORGE EDWARD GARTSIDE.
GEORGE SMITH GOODMAN.
HENRY COLEMAN HEAD.
HENRY HOME.
HENRY COOK LEAKE.

JAMES PONSONBY MAGILL.
PERCIVAL MARSHALL.
WARDEN APPLEBY MOLLER.
HERBERT HENRY NIBLETT.
FRANCIS THURSFIELD, B.A.
THOMAS HARKNESS WATT.
ROBERT WILLISHER WEEKES, Wh.Sc.

The following Candidates were balloted for and duly elected as

Honorary Members.

Dr. WERNER VON SIEMENS.
Field-Marshal Sir JOHN LINTORN
ARABIN SIMMONS, G.C.B., G.O.M.G.,
R.E., Assoc. Inst. C.E.

Sir GEORGE GABRIEL STOKES, Bart.,
F.R.S., D.C.L., LL.D., M.P.

Members.

JOSEPH NAPOLEON DU BARRY.
PATRICK DUNCAN.

CHARLES ANTHONY KIRBY.

Associate Members.

FREDERICK ADAMS, Stud. Inst. C.E.
ERNEST FITZBOY AMES.
GEORGE WILLIAM ANDERSON.
DAVID BALFOUR, JUN., Stud. Inst. C.E.
JOSEPH WILLIAM BARKER, Stud. Inst.
C.E.

THOMAS MACKENZIE BATCHEL, Stud.
Inst. C.E.
EDWIN JAMES BEAL.
HENRY JOHN INWOOD BILTON.
ROBERT HEARN CHARTERS, Stud. Inst.
C.E.

Associate Members—continued.

JOHN JAMES DAVIDGE CLEMINSON, Stud. Inst. C.E.	KENNETH McLAURIN MONTEATH, Stud. Inst. C.E.
WILLIAM COOPER.	DAVID HOME MORTON.
JOHN ROWLAND CROOK, Stud. Inst. C.E.	DANIEL MURBOOTT.
WILLIAM JAMES DAVY.	FRANCIS JOSEPH O'REILLY, Stud. Inst. C.E.
EVAN EVANS.	WILLIAM PARKER.
WILLIAM EVANS.	JAMES LENNOP PROUDFOOT.
RICHARD GORDON HAMILTON.	ARTHUR BANKS RIGBY, Stud. Inst. C.E.
JOHN JAMES HENDERSON.	ERNEST EDWARD SAUNDERS, Stud. Inst. C.E.
GEORGE WILLIAM HOLMES.	ERNEST GEORGE ANGANTYR SCHELE.
JOHN HUDDART.	ROBERT SMITH SCOTT.
CHARLES THOMSON JOHNSON, Stud. Inst. C.E.	JOHN FREDERICK SIMMANOE.
THOMAS KIRKLAND.	PERCY WILSON SYMONS.
THOMAS ROLAND LAUGHARNE.	CHARLES THEODORE HERMANN WEBS.
ARTHUR LAZENBY, B.A., Stud. Inst. C.E.	ALEXANDER WELSH.
MATTHEW LOAM.	RICHARD WILLIAMSON.
MURDOCH MACDONALD, Stud. Inst. C.E.	HARRY WREATHALL, Stud. Inst. C.E.
HERBERT WOODVILLE MILLER.	THOMAS WRIGHT, Stud. Inst. C.E.
	HENRY EDWARD WYNN.

The discussion upon the Paper on "The Bishop Rock Lighthouses," by Mr. W. T. Douglass, and on "The Illumination by Gas of Tory Island Lighthouse," by Mr. David C. Salmond, occupied the evening.

LIST OF MODELS, &c.,

EXHIBITED AT THE MONTHLY RECEPTION, 23 FEBRUARY, 1892.

Exhibitor.	Objects.
APPLEBY BROTHERS . . .	Model of Lighthouse, Straits of Malacca. Model of Mooringa. Model of Pile and Screw. Model of Roadway Bridge erected in Denmark. Photographs (3) of machinery used in construction of sea-coast works and for loading and discharging cargoes.
SIR W. G. ARMSTRONG, MITCHELL & Co.	Model of 100-ton Floating Crane.
ROBERT BAYLY . . .	Chart contrasting the coast communication of the south-west and north-east of England with that of Denmark.
BUOYRUS STEAM SHOVEL AND DREDGING COMPANY, Ohio, U.S.A.	Photographs illustrating American practice in dredging and excavating.
BUTE DOCKS COMPANY . .	Model of the "Lewis & Hunter" coal-shipping appliances.
CLARK & STANDFIELD . .	Model of Improved Bilge-shore. Model of Off-shore Floating Dock. Model of Self-centering Shores.
HENRY J. COLES, M. Inst. C.E.	Model of Dredging Grab.
W. COLSON, Assoc. M. Inst. C.E.	Model showing Cofferdam and method of timbering trenches for the walls of the new entrance to the Tyne Dock. Model showing junction of the hollow quoins and sill stones.
DAVID CUNNINGHAM, M. Inst. C.E.	Model of Portable Hydraulic Jigger, with differential hoisting barrel. Photographs (2) of Cunningham's System of Automatic Tramway.
DAY, SUMMERS & Co. . . .	Model of Floating Pontoon and Shears combined.
FLEMING & FERGUSON . .	Model of Hopper Dredger, with traversing gear, built for the Barry Dock and Railways Company.
GREAT WESTERN RAILWAY COMPANY.	Tide-gauge used by the late Mr. I. K. Brunel.
HADFIELD'S STEEL FOUNDRY COMPANY.	Photographs and specimens of manganese-steel in its application to dock and harbour works.
GEORGE HONE	Model of Crane and Grab.
HUNTER & ENGLISH .	Model of 50-ton Floating Crane "Leviathan."

Exhibitor.	Objects.
DARNTON HUTTON, M. Inst. C.E.	Model of Concrete-block and Disengaging Tackle, showing method of setting blocks under water without a diver.
T. OWEN JACOBSEN . . .	Railway Chairs and Rail Sections.
LE GRAND & SUTCLIFF . .	Model of Electric Standard supported on a dwarf pile, with dwarf pile showing method of hand-driving. Model of Tubular Pile-driver, with tubular pile, showing method of driving at the point instead of upon the head.
LONDON HYDRAULIC POWER COMPANY.	Brotherhood's 3-Cylinder Hydraulic Capstan.
MERSEY DOCK ESTATE . .	Model of the Liverpool Landing-stages. Model of Dock-gate Heel-post.
HENRY POOLEY & SON . .	Model of 20-ton Railway Weighbridge.
PRIESTMAN BROTHERS . .	Model of Grab Dredger and Excavator. Model of Appliances for Discharging Grain, &c.
PULSOMETER ENGINEERING COMPANY.	"Holmes and Ingrey" Automatic Steam Siren for High Pressures. "Ingrey" Sirennetto.
W. C. PUNCHARD, ASSOC. M. Inst. C.E.	Cross section of the La Guaira Breakwater. Model and Photographs of 70-ton Rocking Depositor for bags of concrete.
RANSOMES & RAPIER . . .	Photographs (4) of Titans, &c., in use in Australia.
SIEBE, GORMAN & Co. . .	Diving Helmet, with air-outlet regulator and loud-speaking telephone. Diving Helmet, with Gorman's speaking apparatus—Royal Navy pattern. Gorman's Improved Diving Pump. Submarine Electric Lamps (2).
WILLIAM SIMONS & Co. . .	Model of Dredger "Dolphin." Model of Ferry Steamer "Finnieston." Model of Otago Hopper Dredger. Oil painting of Stern-well Hopper Dredger "St. Andrew." Photograph of Dredger "Melbourne."
SISSONS & WHITE	Working Model of Steam Pile-driver.
STOUGHTON & PITT . . .	Photographs of Plant for Harbour Works. Skeleton Model of Peterhead Titan. Working Model of Single-chain Grab.
F. SUTCLIFFE	Model of Sounding Apparatus.
TELEGRAPH CONSTRUCTION & MAINTENANCE COMPANY.	Model of the "Sunk" Light-vessel, with apparatus for telegraphic communication between her and the shore at Walton-on-the-Naze.
BERNARD TOWNSEND, ASSOC. M. Inst. C.E.	Model of Lighthouse at West End of Plymouth Breakwater. Model of Wall of Alderney Breakwater, with cranes, &c., showing method of executing repairs. Photographs (2) showing method of adjusting counterpoise at Alderney breakwater.

Exhibitor.	Objects.
BERNHARD TOWNSEND, Assoc. M. Inst. C.E.	Specimens of Limestone from Plymouth break- water, bored by the teredo navalis.
TRINITY HOUSE (THE COR- PORATION OF).	Douglass 8-wick Burner (service intensity 1,200 candles). Douglass 10-wick Burner (service intensity 1,800 candles). Fresnel 4-wick Colza-oil Burner (standard inten- sity 230 candles).
TYNE IMPROVEMENT COMMIS- SION.	Model of Concrete Mixer. Model of upper, end of Lock at Albert Edward Dock, showing novel invert apron. Photograph of Model of Mammoth Crane used in the construction of the Tyne South Pier.
WEAR COMMISSION . . .	Model of Bag Barge for lowering concrete bags. Model of the moving of the North Pier Light- house, carried out by the late Mr. John Murray. Plan of Sunderland Harbour and Docks.
W. H. WHEELER, M. Inst. C.E.	Working Model of Dredger. Model of an "Eroder" Dredger.
WHITAKER BROTHERS . . .	Model of Steam-crane Navyy.

SECT. II.—OTHER SELECTED PAPERS.

*(Paper No. 2557.)***Practical Astronomy, as applied to Land-Surveying.**

By ROBERT HENRY BURNSIDE DOWNES, Assoc. M. Inst. C.E.

THE object of this Paper is to present to engineers and surveyors, in a simple and concise form, solutions of the principal practical problems in surveying by aid of astronomical observations, which the Author believes are not given separately elsewhere. It is hoped that the practical surveyor will thus be saved having to wade through long astronomical treatises containing much matter unnecessary for his purpose. These problems of geodesy are, (1) Determination of true North Line or Meridian; (2) Determination of Latitude; (3) Determination of true Mean Time; (4) Determination of the convergence on any line, or system of lines, on the earth's surface.

TRUE NORTH LINE.

There are three principal methods of obtaining a true north line on the ground, namely, (1) by observation of circumpolar stars at elongation; (2) observation of suitable stars at equal altitudes; (3) extra meridian observations of the sun or stars. Of these methods, the first is decidedly the best, because at elongation a star does not move at all in azimuth,¹ and thus allows ample time for the star to be observed on both sides of the vernier plate of the instrument, and the consequent elimination of errors of collimation, or want of horizontality of the horizontal axis; whereas, in other observations, the star crosses the wire of the instrument instantaneously, and may be moving rapidly in azimuth, when the sight cannot be checked; again, because of the extreme simplicity of the calculations necessary, and also because (where the latitude is known, even approximately) the observation only lasts a few minutes, and requires but one set of observations. This is an important advantage, because in the interval of time

¹ A star's azimuth is the arc of the horizon between its direction and the true meridian.

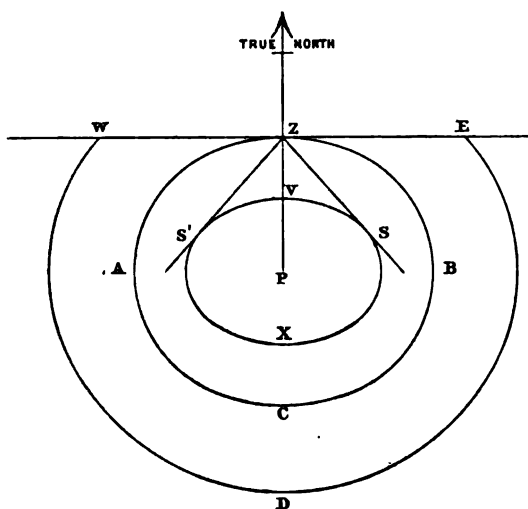
drawn from the observer at Z would be a tangent to the ellipse VS'W. The star would then appear to the observer to cease for a while its motion in azimuth, and to descend vertically for a short time along the vertical wire of the theodolite. After this, it would, whilst still descending, move away to the east until arriving at W—its point of lower culmination—when, continuing its motion in azimuth to the east, it would also ascend again towards the point S, which is its point of greatest eastern elongation. It would now ascend vertically along the vertical wire of the instrument for a short time, and then complete its orbit by moving off upwards and in a westerly direction to V. It is during the elongations, or periods when the star is moving vertically only, that the observation must be taken. The angle SZP or S'ZP is the azimuth angle, or the angle which the line of sight, from the observer Z to the star S or S', makes with the true meridian; and the angle SPZ or S'PZ, or t , is the hour angle, namely, the interval of sidereal time between the star's upper culmination at V and elongation at S or S' expressed in degrees.

All stars with declination greater, or polar distance less, than the latitude of the place, are theoretically available for elongation observations; but practically, stars for this purpose should be from 50° to 80° south declination. A star with its declination the same as the latitude would elongate, but its elongation would be an east or west line, i.e., the prime vertical; whilst a star with declination less than the latitude of the place would cross the east and west line WE, and not elongate. In *Fig. 2*, SVS'X is the orbit of a star with its declination greater than the latitude of the place Z, and which consequently elongates at SS'; ZACB is the orbit of a star with declination the same as the latitude of Z, and ZW or ZE is line of elongation; and WDE is a representation of a star with declination less than the latitude of Z, which would consequently cross the east and west line. The nearer a star is to the pole—that is the greater its declination—the slower its movement generally, and at elongation in particular; whence the stars most used for elongation are as follows: α and β Centauri, the pointers of the Southern Cross, α Argus (Canopus), α Eridani (Achernar), and β Hydræ. These five are exceedingly useful stars; but the best is β Hydræ, as it is nearest to the pole; though, as it is only a third magnitude star, it is at times not easy to find. It lies nearly in a straight line between α Centauri and Achernar, and about one-third the distance from the latter. It is also close to, and slightly nearer the pole than Nebecula Minor, the lesser Magellan cloud. Other useful stars are, α Pavonis, α Gruis

α Reticuli, α, β, γ , Trianguli Australis, and $\alpha, \beta, \gamma, \delta$, Crucis, the stars of the Southern Cross.

Should the observer be unable to obtain even an approximate idea of his latitude, which will rarely be the case, he will require to observe a star at both its elongations; and the bisection of the angle between them will give the true north and south line. Having selected a star which will culminate at about midnight—that is, a star whose right ascension,¹ less twelve hours, will be about the same as the sidereal time² at previous mean noon—observe it early in the evening at its east elongation; that is,

Fig. 2.



watch it until it appears to cease its motion in azimuth, and travel vertically up the vertical wire of the instrument; and, having made sure that this is the case, depress the telescope, and set a point on the ground as far away as can be conveniently seen; then reverse the instrument, and, turning the telescope over, sight again on to the star, and again clamping, make sure that the star has not commenced its westerly motion, but is only moving upward. Again depress the telescope, and if the horizontal axis of the telescope is out of adjustment, and the intersection of

¹ The right ascension of a star is the arc of the celestial equator intercepted between the star's meridian and the vernal equinox.

² Sidereal time is the distance of the first point of Aries from the meridian at mean noon.

the cross hairs not on the first point, set a second; and the point midway between the two will indicate the correct position of the star's eastern elongation. The observer will now have to wait until the morning to observe, and similarly peg down, the western elongation. There will, in the case of most stars, especially those with small polar distance, be ample time to take the observations on each side of the plate. Having carefully fixed the two pegs indicating the bearings of the elongations, and one under the instrument, the observer can wait for daylight to bisect the angle and fix a true meridian peg. This observation, though simple, is very tedious; and it may take several nights before the observer can satisfactorily obtain two elongations, as the sky may become cloudy in the interval. In most cases, it is possible to obtain a close approximation of the latitude by scaling from a map, when the approximate time of elongation can be calculated; and in that case, the calculated azimuth will be within the limits of practice as regards error, and the mean of two azimuths from elongations of two different stars will be a correct north line.

The method of obtaining a meridian from one elongation observation depends on two conditions, the latitude of the place, and the declination of the star. The declination of the star is obtained from the almanack; and the slight variation in the course of a year, owing to the precession of the equinoxes, may usually be ignored, as it is but a few seconds, and an azimuth angle cannot be laid off with a 5-inch theodolite to less than thirty seconds. However, if used, a proportion of the given variation, corresponding to the proportion of the year at the date, should be applied. The latitude is also a fixed quantity, so long as the observer remains at or about the same place. The elongation formulas are as follows:—Let δ = declination of star, ϕ = latitude of place. Then in *Fig. 1*,

$$(i) \angle SZP, \sin \text{azimuth} = \frac{\cos \delta}{\cos \phi} = \text{azimuth from south};$$

$$(ii) \angle ZPS, \cos t = \frac{\cot \delta}{\cot \phi} = \text{hour angle};$$

$$(iii) \sin \text{altitude} = \frac{\operatorname{cosec} \delta}{\operatorname{cosec} \phi} = \text{altitude, or} = \frac{\sin \phi}{\sin \delta}.$$

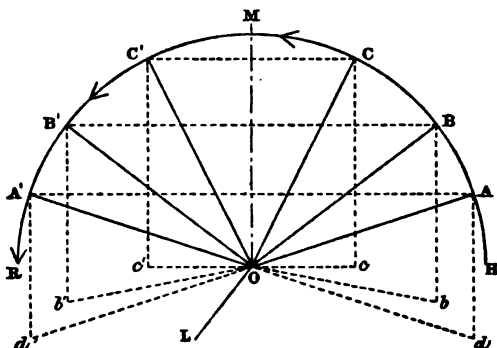
Having observed and pegged down one of the elongations of the star, selected in the manner explained for double elongations, the formula (i) gives the angle of azimuth from the south, or angle between south pole and star at elongation, and by laying this off to the east or west of the pegged line, according as the elongation

was west or east, the true meridian will be obtained. To avoid waste of time, it is convenient to calculate previously the time at which the observation must be made by means of formula (ii), which gives the interval of sidereal time between the upper culmination and elongation in degrees; convert this into hours by dividing by fifteen or by a table; if the elongation be west add this to, and if east subtract this from, the right ascension of the star (obtained from almanack) which is the sidereal time of upper culmination; and the result is the sidereal time of the elongation. From this sidereal time (having, if necessary, increased it by twenty-four hours to keep it a plus quantity) subtract the sidereal time, or the right ascension of the sun, for preceding mean noon, and the result is the interval of sidereal time since preceding mean noon, which must be converted into interval of mean time by the application of the retardation correction from mathematical tables, when it is the true mean time of the elongation at the place. It is advisable to commence to observe the star about ten minutes earlier, to allow for errors of watch, &c. To assist in finding the star, which is sometimes difficult, owing to the small field of the telescope, by employment of formula (iii), the altitude of the star at elongation is obtained. An example of the method is given in Appendix I.

Equal Altitudes of suitable Stars.—This is an extremely simple method of obtaining a true meridian, but it is liable to certain objections, viz., it requires two observations of the same star at considerable intervals of time, during which the atmospheric conditions may have entirely altered, thus admitting errors from refraction, or even concealing the star altogether. Again, the star moves more or less rapidly across the wire in azimuth, and requires a certain amount of skill in the manipulation of the instrument to obtain a reliable result; and even a skilful observer should take two or three pairs of observations, and accept the mean of his results as correct. On the other hand no calculation is required. Let HABCMC'B'A'R (*Fig. 3*) be the path of a star from rising at H to setting at R, M being the point of culmination or meridian passage. Let ABC be three positions of the star, at altitudes 40° , 50° , and 60° , when rising east of the meridian M, and C'B'A', be corresponding altitudes of the star in setting to the west of the meridian. Let O be the station of the observer. Let a suitable star be observed at altitudes A, B, and C, and the bearings Oa , Ob , Oc , carefully pegged down or noted with reference to a referring mark, such as OL, and the operation repeated as the star arrives at the corresponding altitudes C', B', A'; in this case

pegging down or noting Oc' , Ob' , Oa' . Then the mean of the bisection of the angles, aOa' , bOb' , cOc' , may be taken as the meridian

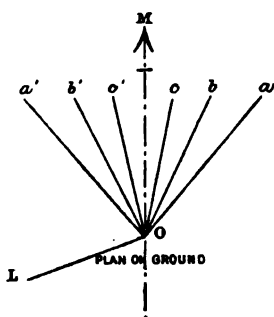
Fig. 3.



line (Fig. 4). If all the different observations were made absolutely accurately, the bisections of these three angles would

be coincident, for a star is at the same azimuth from the meridian at a certain altitude, whether rising or setting. In practice, however, a slight difference is sure to arise; but the mean of two or three pairs of observations may be accepted as a fairly correct meridian. The pairs may be all observed on one star, or may be taken from two or three different stars, the latter being usually the quicker method. Some observers prefer, on having observed the star, to depress the telescope, and peg down the direction, leaving the reading of the hori-

Fig. 4.

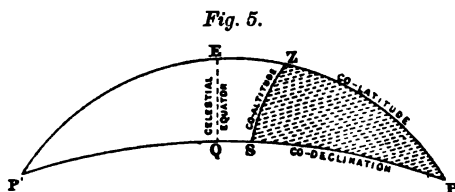


zontal vernier for daylight; others practise reading the vernier, and noting the bearing as related to a referring lamp L. In the former method there is a liability to error, owing to the want of horizontality of the axis of altitude, which may be practically eliminated by observing the rising of the star on one side of the plate, and the setting with the telescope reversed. In the latter method, the telescope is not shifted between the observation and the reading; but it is difficult to read the vernier accurately by the light of the lantern, although in any case the vertical arc must be set by lantern light.

Extra-meridian observations of the Sun or Stars.—This is a very

convenient method of obtaining the required information, because the observation may be made at any time, and the one observation suffices; but the computations are slightly laborious. When the true meridian is required, the method consists in observing the sun or a star at any time, and in any other position than on the meridian; the reduction of the observations; and the computation therefrom of the angle of azimuth of the body at the time of observation, and its relation to a referring mark in point of bearing. The data to be determined by observation are, 1st, The horizontal angle that the celestial body makes with the referring mark at the time of observation; 2nd, The true mean time, or more generally the altitude of the celestial body. If the latitude of the place is known, only the altitude will require to be observed; but if the latitude is not known with sufficient accuracy, both altitude and time must be observed. The data to be obtained from the almanack are the declination of the body in any case, and the right ascension of the body, with the sidereal time at previous mean noon, if the time be observed; and also the semi-diameter and equation of time for the day, if the observed body be the sun.

In *Fig. 5*, the shaded portion SPZ is the astronomical triangle, PEZP is the meridian of the place of observation, P'QSP that of the body, Z is the zenith of the observer, P is the south pole, S the celestial body, and EQ the celestial equator. EZ is the latitude of



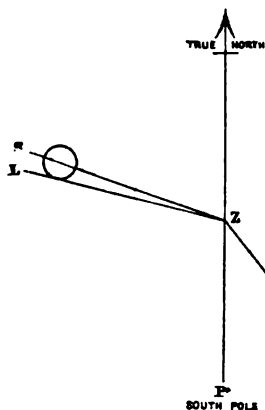
the place, hence ZP is the co-latitude; QS is the declination of the body, hence SP is the co-declination; and as the arc from S to the horizon is the altitude, SZ is the co-altitude, or also the zenith distance, and PS the south polar distance. The angle SZP is the azimuth angle, or angle between the body and the pole, and SPZ is the hour angle, or angle between the meridian of the body and that of the place of observation; and ZSP is the parallactic angle at the body. Now, having obtained, by observation and reference to the almanack, the bearing of the body as related to the referring mark, the declination, altitude, and latitude, the complements of which are the three sides of the triangle SZP, the azimuth angle SZP is computed by means of the formula,

$$\tan \frac{SZP}{2} = \frac{1}{\sin(S-SP)} \sqrt{\frac{\sin(S-SP) \sin(S-SZ) \sin(S-PZ)}{\sin S}}$$

which is the angle between the body and the true meridian required. By applying this to the bearing obtained, as related to the referring mark, the true bearing of the referring mark is obtained, whence the true meridian can be laid off.

If the celestial body be a star, then the angle so obtained will be the true azimuth angle SZP (*Fig. 6*), and may be at once

Fig. 6.



applied to ZR, the referring line; but if it be the sun, the calculated angle is still SZP, the angle to the sun's centre; and if the bearing observed has been to the sun's right or left limb L (*Fig. 6*), it is necessary to connect the two angles by applying the sun's semi-diameter in azimuth, which is the semi-diameter (obtained from the almanack) multiplied by the secant of the altitude, and then deducing the true bearing of ZR.

If the computation is worked from the hour angle SPZ (*Fig. 5*), deduced from true mean time, instead of the co-altitude ZS, SP, ZP, and the angle SPZ, are known in the triangle SPZ, when it will be necessary to use the first pair of Napier's analogies,

$$\tan \frac{SZP - ZSP}{2} = \frac{\sin \frac{SP - PZ}{2}}{\sin \frac{SP + PZ}{2}} \cot \frac{ZPS}{2}, \text{ and}$$

$$\tan \frac{SZP + ZSP}{2} = \frac{\cos \frac{SP - PZ}{2}}{\cos \frac{SP + PZ}{2}} \cot \frac{ZPS}{2},$$

whence, having obtained half the sum and half the difference of the two unknown angles, the two angles can be obtained and located by the rule that the greater angle is subtended by the greater side. The angle SZP is then applied as before.

Should the latitude not be known to a sufficient degree of accuracy, it will be necessary to observe both altitude and true mean time, in which case the known parts of the triangle SPZ

(Fig. 5) will be SZ, SP and $\angle SPZ$; and the angle SZP must be obtained by the rule of sines;

$$\frac{\sin SZP}{\sin SP} = \frac{\sin SPZ}{\sin SZ}, \text{ or } \sin SZP = \frac{\sin SP \sin SPZ}{\sin SZ},$$

and applied as before. If there is any ambiguity about the angle SZP so obtained, namely, whether the required angle should be the angle obtained by calculation or its supplement, it will generally be found that the larger of the two quantities is the one required, especially if the body observed be the sun; but there will only be difficulty in deciding when the angle is nearly a right angle.

The altitude obtained on the vertical arc is the observed altitude, and must be converted into apparent altitude by the elimination of index error (if any), and dip of the horizon if the instrument used be a sextant; and this must be further reduced to true altitude before being ready for use. In the case of a star, this consists in merely deducting the mean refraction for the altitude; but in the case of the sun, there are more corrections, in which some of the quantities are plus and some minus; and these corrections must always be applied in the same order, viz., observed altitude $\pm$ index error gives apparent altitude, and apparent altitude $-$ mean refraction $\pm$ sun's semi-diameter $+$ parallax gives true altitude. If it is desired to obtain both altitude and bearing of the sun, as it is not easy to observe both the lower (or upper) and the right (or left) limb at the same moment, it will often be best to observe the right or left limb, and read the altitude of the centre of it as nearly as possible, in which case the correction for sun's semi-diameter in altitude will be unnecessary. Celestial bodies should never be observed at altitudes less than 15° or 20° , because at low altitudes the element of refraction is extremely variable.

DETERMINATION OF LATITUDE.

The four principal methods of obtaining latitude are as follows: 1. Meridian altitudes of the sun or stars; 2. Zenith pair observations of suitable stars; 3. Prime vertical observations; and 4. Extra meridian observations of sun or stars, the last of which is similar to method (3), for true north line.

Meridian Altitudes of the Sun or Stars.—This is by far the most simple and usual method of obtaining latitude. Figs. 7 to 12 show all possible cases of meridian altitudes of the stars or sun. HOR is the horizon, H the north, R the south, and Z

the zenith of the observer. P is the south pole, E the intersection of the celestial equator with the meridian, S the star or sun's centre, and L the sun's lower limb. HZR is the meridian of the place of observation O (the earth being reduced to a point in comparison with the vast distances of the stars), HZR being the semicircle traced out upon the sky by a theodolite set up on a true north and south line and transited. For the observation, the instrument must be set up on a true north and south line, and the altitude of the star or sun's limb (upper or lower) observed. The altitude so obtained is to be converted into true

Fig. 7.

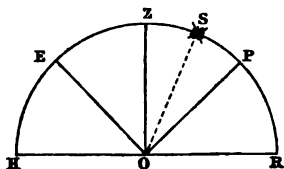


Fig. 8.

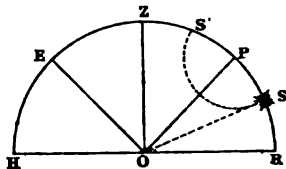


Fig. 9.

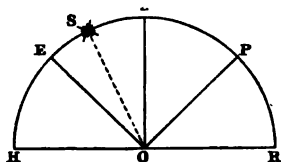


Fig. 10.

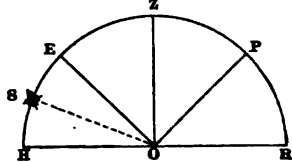


Fig. 11.

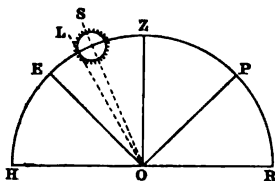
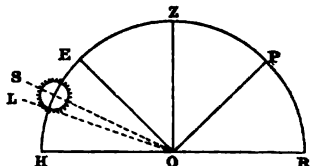


Fig. 12.



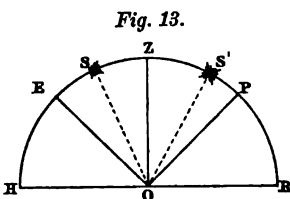
altitude, which must then be applied to the declination—north or south—of the celestial equator by addition or subtraction. Thus having altitude SH or SR, and declination SE (Figs. 7 to 12), HE or RE must be deduced, and hence the latitude EZ or PR of the place of observation. It is advisable to ascertain the time of the meridian transit previous to the observation, to prevent delay. In the case of the sun, this simply amounts to applying the equation of time for the day to mean noon, and thus obtaining the

true mean time at which the transit will take place. Thus if it had been desired to observe the sun's meridian passage on September 30th, 1889, the equation of time being - 10 minutes for apparent time, the meridian passage will have been at fifty minutes past eleven A.M.

In the case of a star, the mean time may be at once determined with sufficient accuracy by means of the planisphere. Otherwise obtain its right ascension from the almanack, which is the sidereal time of upper culmination or meridian transit, and reduce it to mean time by subtracting the sidereal time of previous mean noon (obtained from almanack), thus obtaining the interval of sidereal time between previous mean noon and meridian transit, which must be converted into mean time by table, the result being true mean time of transit, because the astronomical or mean day starts at noon. In such a case as shown in *Fig. 8*, in which it is the lower culmination that is observed, it will be necessary to apply twelve hours to the right ascension before making the above conversion. An example of this method is given in Appendix III.

Zenith Pair observations of suitable Stars.—This method, which is only applicable to stars, is an adaptation of the last method, in which, by observing the meridian transit of two stars, one on either side of the zenith at almost equal altitudes, the sources of error from refraction and imperfect graduation of the vertical arc of the instrument are practically eliminated. Two stars must be selected which culminate at almost equal altitudes, and within a short time—say half an hour—of each other, and their altitudes at transit observed with the instrument set up on a true north and south line, as in method (1) (*Fig. 13*). These altitudes must be corrected for refraction, and then the complements, or zenith distances, applied to one another, and the difference deduced, thus obtaining $SZ - S'Z$. Obtain from the almanack the declinations ES , ES' , and thence deduce $SZ + S'Z$, the sum of the zenith distances, $= SS'$.

Then $\frac{SS'}{2}$, plus or minus half the zenith

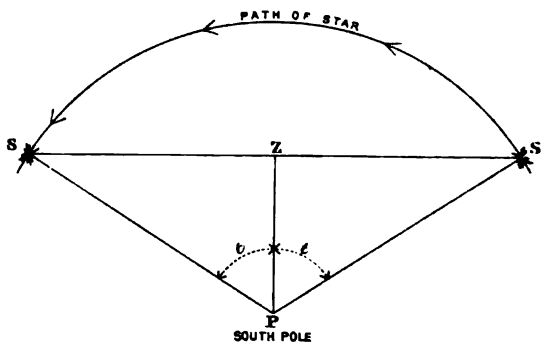


differences, will give SZ or $S'Z$, as preferred; and this applied to the declination of S or S' (according to which zenith distance was used) will give EZ , the latitude required. This method is equivalent to a mean of two observations similar to method (1), with the advantage of similarity of atmospheric conditions, owing to the observations being taken within such a short time of one

another, thus equating refractions. The stars can best be selected by the aid of the planisphere. (For example, see Appendix III.)

Prime Vertical observations of Stars.—This is the most exact and scientific method of all; but it requires powerful instruments, and exact chronographic apparatus, and is, therefore, only suited for fixed observatories or geodetic camps. Stars with declination between 0° (celestial equator), and the latitude of the place of observation, will cross the prime vertical, or true east and west line, twice each day, and it is the times of these transits only which require to be observed; but as an error of four seconds in the observation of time will make an error of one minute in arc, unless the arrangements for measuring the times are very exact, the result will only be approximate, more especially as a minute represents something over a statute mile on the surface of the earth. Although all stars whose declination lies between 0° and the latitude of the place are theoretically available for this observation, the practical limits in these latitudes (30° to 40°) is from about 10° to 30° south declination. Having selected a suitable star, observe its two prime vertical transits; and the difference of these observed times (true mean) expressed in sidereal time and turned into arc, is the angle SPS' , and half this is the angle SPZ , or hour angle t (*Fig. 14*). Then, having obtained from the almanack the declination of the star,

Fig. 14.

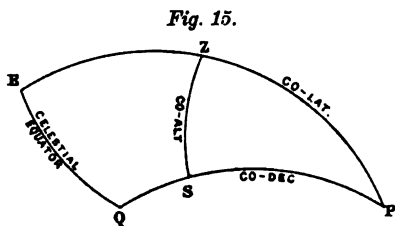


two quantities t and δ are known of the three, t , δ , and ϕ , which are connected by the formula $\cos t = \frac{\tan \delta}{\tan \phi}$, whence $\tan \phi = \frac{\tan \delta}{\cos t}$ from which the latitude ϕ is computed. Observations on a true east and west line relate only to stars as a rule, though under certain circumstances the sun can be thus used in these latitudes.

To avoid loss of time, it is convenient to know the approximate times of the observations. These may be obtained from the planisphere, or by adopting an approximate latitude obtained by scaling from a map or otherwise, and by the use of the formula $\cos t = \frac{\tan \delta}{\tan \phi}$, giving the hour angle t , which is reduced to mean time as explained on p. 255. The observation should be commenced about ten minutes before the time so obtained. Three prominent and useful stars for this class of observation, are Sirius, Antares, and Fomalhaut. The principal instrumental error to be guarded against, is want of horizontality of the horizontal axis. An example of the method will be found in Appendix III.

Extra Meridian observations of Sun or Stars.—This method is similar to method (3) of true north line. The celestial body is observed anywhere off the meridian; and the latitude is computed by means of the astronomical triangle (Fig. 15). Obtain by observation and reference to the almanack any three out of the four quantities SP (co-dec.), SZ (co-alt.), SZP (azimuth), and SPZ (hour angle), and then determine the fourth by the spherical rule of

sines formula, $\frac{\sin A}{\sin a} = \frac{\sin B}{\sin b}$



$= \frac{\sin C}{\sin c}$. SP, the co-declination, will always be derived from the almanack; and the usual conditions to be observed are the altitude and the azimuth where the true meridian line is known; the formula will then become $\sin SPZ = \sin SZ \frac{\sin SZP}{\sin SP}$. In the absence of a true north line, the mean time of the observation must be observed with a more closely divided timekeeper than an ordinary watch. The observed time must be converted into hour angle, when the formula will become $\sin SZP = \sin SP \frac{\sin SPZ}{\sin SZ}$. Having thus obtained the four quantities, SP, SZ, SZP, and SPZ, the co-latitude PZ must be obtained by the formula,

$$\tan \frac{PZ}{2} = \frac{\sin \frac{SZP + SPZ}{2}}{\sin \frac{SZP - SPZ}{2}} \tan \frac{SP - SZ}{2}$$

as PZ is required; and the angles SZP and SPZ being given, both their sum and difference is known. Having obtained half the co-latitude by the formula, the latitude can be readily deduced. (For example, see Appendix III.)

TRUE MEAN TIME.

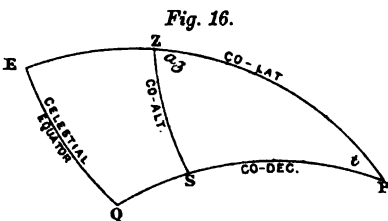
There are three practical methods of obtaining the true mean time—1. By meridian transits of sun or stars; 2. By telegraph; 3. By extra meridian observations of sun or stars; but only the last can be said to come properly under the head of geodesy.

Meridian Transits of Sun or Stars.—This method is only suitable for a fixed observatory, where there are powerful and complicated instruments most accurately fixed on the true meridian, and provided with electric recorders to mark the transits. Under these circumstances, the time can be taken to less than one-tenth of a second. With a theodolite and watch, the results would be unreliable, however careful and practised the observer. The transit of the selected celestial body over five or seven wires, of which the central one represents the true meridian, is observed; and the chronometer, or mean time of the exact moment of transit, is noted. If the body is the sun, this transit occurs at apparent noon, and needs only the application of the equation of time for the day to be converted into true mean time. The times of transit of each limb (preceding and following) over every wire used, has to be noted, and the mean of them all adopted as the true instant of the central passage, or the true apparent noon. If the body be a star, the moment of transit represents the sidereal time of culmination, or the right ascension of the star. This, taken from the almanack, and interpolated if necessary for longitude, is, therefore, the sidereal time at the moment of transit, and must be converted into mean time by deducting the sidereal time of previous mean noon from it, and by correcting the resulting interval of sidereal time for retardation.

By Telegraph.—This method, though impracticable in the field, is of great practical and commercial utility. The time is sent by telegraph from some observatory, or place where the correct time is known, and corrected for longitude by turning the longitude in arc into time, and adding it to the mean time if the longitude of the receiving station be east, or subtracting if it be west of the observatory.

Extra Meridian observations of Sun or Stars.—This is the only method of obtaining true time suitable to the surveyor in the field,

and is similar to the extra meridian observations before treated upon. It is necessary to have either the correct latitude, or a true north line to work upon. Then, having observed the required conditions of the body, the hour angle t is deduced by means of the astronomical triangle (*Fig. 16*). The declination, or rather co-declination SP of the body is obtained from the almanack; and if the latitude or co-latitude ZP is known, either ZS the co-altitude, or SZP the azimuth angle, must be obtained by observation, and, the hour angle SPZ, computed

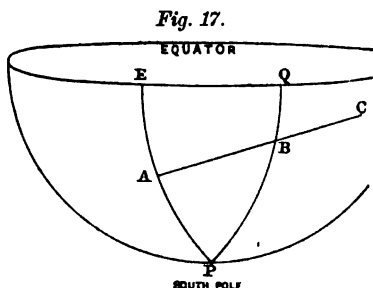


by the rule of sines formula, if it is the azimuth SZP that is observed, or by the "S" formula, if the altitude be observed. If the latitude is not known, ZS (co-altitude) and $\angle$ SZP must be obtained by observation; and the hour angle can be calculated by rule of sines formula. If the body observed is one of the sun's limbs, make the necessary calculations to obtain the sun's centre, as before explained on p. 258, for azimuth, and on p. 259 for altitude; and the resulting angle gives the apparent time in degrees direct, which only requires conversion into time, and the application of the equation of time for the day to be true mean time, that is if the sun be observed west of the meridian; whilst if the sun be observed to the east, the result must be subtracted from twenty-four hours to give true mean time, or from twelve hours for civil time. If the hour angle be large, and the time be required with great accuracy, the equation of time for the day must be computed for the hour. If the body be a star, the calculated angle t is the interval of sidereal time between the observation and the star's upper culmination; and the true time must be deduced therefrom. An example of this method of finding the true mean time is given in Appendix IV.

CONVERGENCE OF MERIDIANS.

Convergence denotes the change in bearing of a line, running straight over the earth for some considerable distance, due to the fact that the meridians to which its bearings are referred, converge to the pole. Thus, if ABC (*Fig. 17*) represents such a line, which is an arc of a great circle on the earth, the only line a theodolite properly set up and levelled can run, as the telescope, on being transited, would point to the centre of the earth when down-

ward. EP, QP, are meridians, P is the pole. The convergence on the line AB is the angular difference EAB-QBC or EAB-ABP. As the exterior angle EAB of the triangle ABP is always greater than the interior alternate angle ABP, the true bearing of an easterly line, such as AB in the southern hemisphere, is constantly though slightly diminishing, as its distance from A increases. The formula used for ascertaining this angular difference



is as follows:—Let c = the convergence in seconds; P = difference of longitude in seconds between the two extremities of the line AB, or the angle APB (*Fig. 17*); ϕ = the latitude of A; ϕ' = the latitude

of B; then $c = \frac{P \sin \frac{\phi + \phi'}{2}}{\cos \frac{\phi - \phi'}{2}}$. When A and B are in the same, or

nearly the same latitude, that is when the line runs quite, or nearly, due east and west, ϕ virtually = ϕ' ; therefore, $\frac{\phi + \phi'}{2} =$

$\frac{2\phi}{2} = \phi$, and $\cos \frac{\phi - \phi'}{2} = \cos \frac{0^\circ}{2} = \cos 0^\circ$, or nearly so; but $\cos 0^\circ = 1$;

and the formula becomes, $c = \frac{P \sin \phi}{1} = P \sin \phi$.

Under such conditions, especially if AB is not longer than twenty-five or thirty miles, the following formulas are sufficiently accurate: $c = P \sin \phi$; $AB = P \cos \phi$; $c = AB \tan \phi$; where AB = the arc of a great circle (*Fig. 18*) reduced from miles or feet to seconds. The following is a frequent case: ABCD (*Fig. 19*) is a geodetic block, bounded east and west by meridians EP and QP, and north and south by great circles, AXB and DVC, perpendicular to a central meridian PVY bisecting the block; and the measurement of the sides and angles are required. Let EP and QP be respectively the 143° and 144° meridians of longitude, and the points A and B on the 36° parallel of latitude, and C and D on the 37° parallel. Then to determine the angles at A and B—

$$\angle (EAB - ABP) = P \sin \phi \quad P = 1^\circ = 3600''$$

$$\therefore \angle (EAB - ABP) = 3600 \sin 36^\circ = 3600 \times 0.5878 = 2116.08''$$

Let the angular difference YAX or YBX, between the parallel of latitude AYB and the great circle AXB = m . Then, since the parallel of latitude is at right angles to all meridians intersecting it, the convergence (EAB - ABP) = $(90 + m) - (90 - m) = 2m$, EAY and YBP being right angles; and therefore m = half the convergence. Hence $YAX = m = \frac{c}{2} = \frac{2116''}{2} = 1058'' = 17' 38''$; and XAP and XBP, the angles at the two northern corners of the block, are each $90^\circ - (17' 38'') = 89^\circ 42' 22''$; and the bearing AB is $90^\circ + (17' 38'') = 90^\circ 17' 38''$ at A, and is $270^\circ - (17' 38'') = 269^\circ 42' 22''$ at B. The equal angles ADC and BCD, the angles at the two southern corners of the block, will each be $90^\circ + m$, in this case being half the convergence on the 37° parallel, to be obtained in the

Fig. 18.

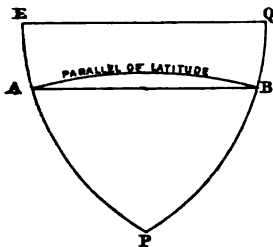
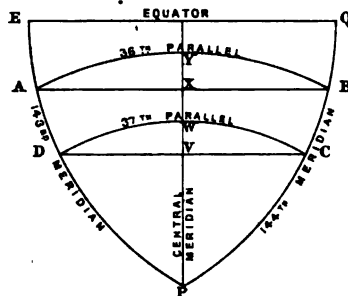


Fig. 19.

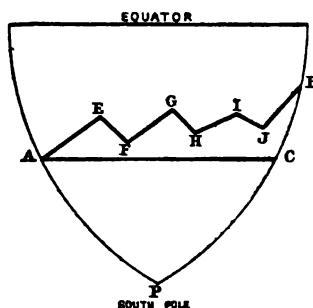


same manner. The lengths of the two sides AB and DC may be obtained by solving the triangles AXP and DVP, in which the angles XAP, APX, and VDP are known, whence AX and DV can be obtained; and these are respectively half AB and DC, or AB and CD may be obtained quicker by the formula $AB = P \cos \phi$. The sides AD and BC are given as one degree of latitude. These sides being known in arc, must be converted into miles, or other lineal measure, by applying the radius of the earth, which at the equator is 20,932,600 English feet. If great accuracy be required, the earth being a spheroid, the radius for the latitude in question must be obtained from geodetic tables.

Finally, the area of the block may be calculated by taking the area of the triangle DPC from that of the triangle APB, which areas must be obtained by the formula—

$$\text{Area of triangle} = \frac{\text{spherical excess}^\circ}{180^\circ} \times \pi r^2.$$

Fig. 20 shows a system of lines, AEF^gHIJB, forming a traverse of considerable extent, in which the convergence is to be ascertained, First determine the total departure, or difference of longitude between the



points A and B, which is AC, then the convergence between the points A and B will be AC, in seconds, $\times \tan \phi$, where ϕ should be the mean latitude between A and B, whether AB is one straight line, or a system of lines as in the figure. The convergence, therefore, on any line or system of lines is equal to the total

departure of the line or system of lines, multiplied by the tangent of the mean latitude.

APPENDIXES.

APPENDIX I.

EXAMPLE OF FINDING TRUE NORTH LINE BY ELONGATION METHOD.

It was desired to ascertain the true bearing of a surveyed line, Z R, of which the instrumental bearing was $179^{\circ} 58' 30''$ (Fig. 21). The sidereal time, at previous mean noon, was 12h. 26m. 30s. The declination of the selected star, α Trianguli Australis, was $68^{\circ} 49' 6''$ S., and the right ascension 16h. 36m. 43s. The western elongation was observed, and the instrumental bearing was found to be $207^{\circ} 12' 30''$.

The latitude of the place was $37^{\circ} 50' \text{ S.}$;

$$\sin \text{altitude} = \frac{\operatorname{cosec} \delta}{\operatorname{cosec} \phi} = \frac{\operatorname{cosec} 68^{\circ} 49' 6''}{\operatorname{cosec} 37^{\circ} 50'} = \sin 41^{\circ} 8'.$$

Therefore the star was to be searched for at altitude $41^{\circ} 8'$;

$$\cos t = \frac{\cot \delta}{\cot \phi} = \frac{\cot 68^{\circ} 49' 6''}{\cot 37^{\circ} 50'} = \cos 72^{\circ} 29' 9'' = \text{hour angle } 72^{\circ} 29' 9'' = \text{in time } 4\text{h. } 49\text{m. } 56\cdot36\text{s.}$$

$$\therefore \text{Interval of sidereal time between } \left. \begin{array}{l} \text{culmination and elongation} \end{array} \right\} = \begin{array}{r} \text{H.} \\ 4 \end{array} \begin{array}{r} \text{M.} \\ 49 \end{array} \begin{array}{r} \text{S.} \\ 56\cdot36 \end{array}$$

$$\left. \begin{array}{l} \text{Sidereal time of upper culmination, or} \\ \text{right ascension of star; to be added} \\ \text{because culmination is earlier than} \\ \text{elongation} \end{array} \right\} = \begin{array}{r} 16 \quad 36 \quad 43 \end{array}$$

$$\therefore \text{sidereal time of west elongation is } \begin{array}{r} 21 \quad 26 \quad 39\cdot36 \end{array}$$

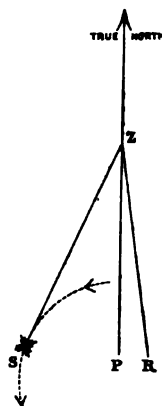
$$\text{Sidereal time of previous mean noon is } \begin{array}{r} 12 \quad 26 \quad 30 \end{array}$$

$$\therefore \text{Interval of sidereal time between } \left. \begin{array}{l} \text{elongation and previous mean} \\ \text{noon} \end{array} \right\} = \begin{array}{r} 9 \quad 0 \quad 9\cdot36 \end{array}$$

$$\left. \begin{array}{l} \text{Retardation of sidereal time on mean} \\ \text{time} \end{array} \right\} = \begin{array}{r} 0 \quad 1 \quad 28\cdot49 \end{array}$$

$$\left. \begin{array}{l} \text{Interval of mean time between elonga-} \\ \text{tion and previous mean noon, which,} \\ \text{in this case, is both true mean and} \\ \text{civil time} \end{array} \right\} = \begin{array}{r} 8 \quad 58 \quad 40\cdot87 \end{array}$$

Fig. 21.



Therefore, the elongation was to be expected at 8 h. 58 m. p.m.

$$\sin \text{azimuth} = \frac{\cos \delta}{\cos \phi} = \frac{\cos 68^{\circ} 49' 6''}{\cos 37^{\circ} 50'} = \sin 27^{\circ} 13' 31'' = \text{angle } SZP, (\text{Fig. 21}),$$

the angle the star made at elongation to the west of the south line ZP.

∴ Azimuth angle west of south	=	27	13	31
		180	0	0
∴ True bearing of star's elongation	=	207	13	31
Instrumental bearing of star was		207	12	20
∴ Variation of instrumental bearings east of south =		1	11	
Instrumental bearing of survey line Z R, Fig. 21, was		179	58	30
∴ True bearing of survey line Z R	=	179	59	41

APPENDIX II.

CATALOGUE OF TWENTY-FOUR SOUTH CIRCUMPOLAR STARS.

(Compiled from the "Victorian Institute of Surveyors' Star Catalogue 1880.")

No.	Name of Star.	Mean Right As-	Annual	Mean South De-	Annual	Magni-
		cension, 1890, January 1st.		clination, 1890, January 1st.		
		H. M. S.	Seconds.	° ' "	Seconds.	tude.
1	β Hydræ . . .	0 19 58.01	+3.260	77 52 25.4	-20.3	3
2	α Eridani (Achernar) . . .	1 33 36.98	+2.240	57 47 48.9	-18.4	1
3	γ Hydræ . . .	3 48 56.78	-1.006	74 34 32.1	-11.0	3
4	α Doradus . . .	4 31 37.33	+1.294	55 16 20.9	-7.6	3
5	β Doradus . . .	5 32 40.24	+0.514	62 33 42.7	-2.4	4
6	α Argus (Canopus) . . .	6 21 30.57	+1.330	52 38 9.0	+1.9	1
7	γ Argus . . .	8 6 8.70	+1.852	47 0 44.7	+10.5	2
8	β Argus . . .	9 11 59.47	+0.682	69 15 49.8	+14.8	1½
9	ω Argus . . .	10 11 7.08	+1.424	69 29 29.0	+17.8	3
10	λ Centauri . . .	11 30 42.43	+2.732	62 24 41.4	+19.9	3
11	α Crucis (mean) . . .	12 20 29.19	+3.281	62 29 22.2	+20.0	1
12	β Crucis . . .	12 41 17.79	+3.458	59 5 13.4	+19.8	2
13	β Centauri . . .	13 56 3.83	+4.174	59 50 31.4	+17.6	1
14	α^2 Centauri . . .	14 32 7.72	+4.032	60 23 0.8	+15.3	1
15	γ Trianguli Australis . . .	15 8 38.90	+5.506	68 16 20.3	+13.7	3
16	β Trianguli Australis . . .	15 45 27.30	+5.228	63 5 23.7	+11.6	3
17	α Trianguli Australis . . .	16 37 1.29	+6.292	68 49 27.4	+7.2	2
18	α Aræ . . .	17 23 20.26	+4.626	49 47 15.9	+3.3	3
19	σ Octantis . . .	18 42 25.94	+108.273	89 16 1.1	-2.1	5½
20	α Pavonis . . .	20 16 56.49	+4.784	57 5 10.8	-11.2	2
21	γ Pavonis . . .	21 17 20.55	+5.044	65 51 45.5	-16.0	4
22	α Gruis . . .	22 1 17.81	+8.808	47 29 35.1	-17.2	2
23	β Gruis . . .	22 36 5.78	+3.612	47 27 32.9	-18.7	2
24	γ Tucanæ . . .	23 11 0.27	+3.540	58 50 18.0	-19.7	4

APPENDIX III.

EXAMPLES OF DETERMINATION OF LATITUDE.

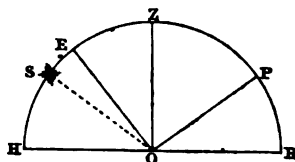
By Meridian Altitude of Star.

On October 20th, 1889, at Zea, Markab α Pegasi was observed on the meridian for latitude. The apparent altitude was $38^{\circ} 11\frac{1}{2}'$. The declination, adjusted for the month of the year, was ascertained to be $14^{\circ} 36' 45''$ N. The right ascension, similarly adjusted, was 22h. 59m. 14s., and sidereal time at previous mean noon 13h. 54m. 57s. (Fig. 22).

	H.	M.	S.
Sidereal time of meridian transit	22	59	14
" " previous mean noon	13	54	57
Interval of sidereal time between previous mean } noon and observation	9	4	17
Retardation	0	1	29.18
True mean time of observation	9	2	47.82

Fig. 22.

	°	'	"
Apparent altitude	38	11	30
Refraction	0	1	12
True altitude	38	10	18



Declination	14	36	45 N.	= $\angle$ SOE.
Altitude	38	10	18	= $\angle$ SOH.
	52	47	3	= $\angle$ HOE.
	90	0	0	
	37	12	57	= $\angle$ EOZ = latitude.

Therefore latitude is $37^{\circ} 12' 57''$ S.

By Zenith Pair Observations of Stars.

At Zea, October 20th, 1889, zenith pair observation for latitude: (Fig. 23).

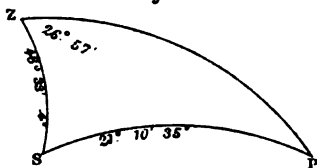
	°	'	"
γ Pegasi, declination (adjusted)	14	34	15 N.
apparent altitude	38	13	45
δ Hydrae, declination (adjusted)	77	53	3 S.
apparent altitude	49	21	0

By Extra Meridian Observation.

As it is a good plan to observe the time of the observation, in order to check the observation generally, so as to ascertain that no radical error has occurred, the time reduction is given in this example, although not absolutely necessary.

On October 20th, 1889, at 7h. 22m. p.m at Zea, for latitude, α Trianguli Australis was observed from a true meridian. Observed apparent altitude, $41^{\circ} 28'$; azimuth, $62^{\circ} 57'$ west of south; declination, $68^{\circ} 49' 25''$; right ascension, 16h. 37m.; sidereal time at previous mean noon, 13h. 54m. 57s. (Fig. 24.)

Fig. 24.



Apparent altitude.	41	28	0	Declination .	68	49	25
Refraction . . .		1	4		90	0	0
True altitude . .	41	26	56	Co-declination	21	10	35
	90	0	0				
Co-altitude . . .	48	33	4				

$$\sin P = \frac{\sin 48^{\circ} 33' 4'' \sin 26^{\circ} 57'}{\sin 21^{\circ} 10' 35''} = \sin 70^{\circ} 6' 57''.$$

As there is nothing in the formula to show whether this angle, or its supplement $109^{\circ} 53' 3''$, should be used, it is advisable to check the time, as that will indicate which is correct.

Hour angle $70^{\circ} 6' 57'' =$ in time . . .	H.	M.	S.
Right ascension	4	40	27.48
	16	37	0
Sidereal time of observation	21	17	27.48
" " " previous mean noon . . .	13	54	57
Interval of sidereal time	7	22	30.48
Retardation		1	12.48
True mean time of observation	7	21	18
Observed time by watch	7	22	0
Watch was fast	0	0	42

This indicates that the angle used is the correct one, and also that there is at least no great inaccuracy in the observed azimuth and altitude.

Next—

$$\tan \frac{\text{co-lat}}{2} = \frac{\sin \frac{70^{\circ} 6' 57'' + 26^{\circ} 57'}{2}}{\sin \frac{70^{\circ} 6' 57'' - 26^{\circ} 57'}{2}} \times \tan \frac{48^{\circ} 33' 4'' - 21^{\circ} 10' 35''}{2}$$

$$= \frac{\sin 48^\circ 31' 58\frac{1}{2}''}{\sin 21^\circ 34' 58\frac{1}{2}''} \tan 13^\circ 41' 14\frac{1}{2}'' = \tan 26^\circ 23' 11\frac{1}{2}''$$

$$\therefore \text{co-lat} = 52^\circ 46' 33'', \text{ and } \therefore \text{latitude} = 37^\circ 13' 37'' \text{ S.}$$

It will be noticed that this latitude differs slightly from those previously obtained. The same instrument being used, there were two verniers to be read, neither of which was divided closer than to minutes; and so, probably, there is a slight error in the reading of each vernier, owing to the impossibility of measuring accurately with the eye only.

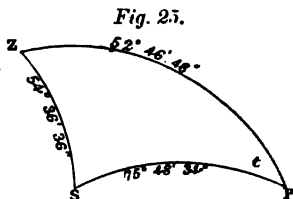
APPENDIX IV.

EXAMPLE OF FINDING THE TRUE MEAN TIME BY EXTRA MERIDIAN OBSERVATIONS.

Observation for true mean time and longitude, at Zea, October 31st, 1889:—

Latitude, $37^\circ 13' 12''$ S.; observed altitude of sun's upper limb, $35^\circ 40' 45''$; time by stop watch, 3h. 27m. 17s. p.m., which was indicated by telegraph to be 40s. fast by Melbourne time. Sun's declination apparent noon, October 31st, $14^\circ 8' 26''$ S.; sun's declination apparent noon, November 1st, $14^\circ 27' 47''$ S.; sun's semi-diameter, $16' 9''$; equation of time, $16' 17''$, to be subtracted from apparent time; longitude of Melbourne, 9h. 39m. 54.8s. E., or in arc, $144^\circ 58' 32''$ E. (*Fig. 25.*)

o	'	''	
14	27	47	sun's declination apparent noon, November 1st.
14	8	26	„ „ „ October 31st.
8)	0	19	21 difference due to 24h.
	2	25	„ „ 3h. 0m.
		24	„ „ 0h. 30m.
		8	„ „ 0h. 10m.
		3	„ „ 0h. 4m.
	3	0	„ „ 3h. 44m.
	14	8	26 sun's declination, October 31st, apparent noon.
	14	11	26 „ „ at time of observation.
	90	0	0
	75	48	34 = co-declination.



Approximate mean time		h.	m.	s.
Equation of time.		3	27	17
Approximate apparent time.		3	43	34
				say, 3h. 44m.

	°	'	"
Observed altitude sun's upper limb	35	40	45
Refraction.		1	19
	35	39	26
Sun's semi-diameter		16	9
	35	23	17
Parallax			7
True altitude sun's centre	35	23	24
	90	0	0
Co-altitude	54	36	36
Latitude	37	13	12
	90	0	0
Co-latitude	52	46	48

$$\tan \frac{P}{2} = \frac{1}{\sin(s-p)} \sqrt{\frac{\sin(s-p) \sin(s-3) \sin(s-s)}{\sin S}}$$

°	'	''	°	'	''		°	'	''
54	36	36 = p	91	35	59		91	35	59
52	46	48 = s	54	36	36		52	46	48
75	48	34 = 3					75	48	34
			36	59	23 = (s - p)				
2)	183	11	58						
	91	35	59 = S.						

$$\tan \frac{P}{2} = \frac{1}{\sin 36^{\circ} 59' 23''} \sqrt{\frac{\sin 36^{\circ} 59' 23'' \sin 38^{\circ} 49' 11'' \sin 15^{\circ} 47' 25''}{\sin 91^{\circ} 35' 59''}}$$

9.7793596	10.0
9.7971789	9.7793596
9.4847555	
	0.2206404
29.0112940	
9.9998306	
2) 19.0114634	
9.5057317	
0.2206404	

$$0.7263721 = \tan 28^{\circ} 2' 17\frac{1}{2}'' = \frac{P}{2}$$

$\therefore P = 56^{\circ} 4' 35'' =$ hour angle = in time	^{H.} 3	^{M.} 44	^{S.} 18.20
equation of time . . .	0	16	17
true mean time . . .	3	28	1.20
observed time . . .	3	27	17.00
watch was slow . . .	0	0	44.20

Watch was	^{M.} 0	^{S.} 44	slow by true mean time at Zea.
"	0	40	fast " " Melbourne,

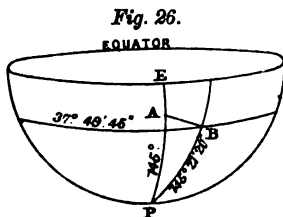
" 1 24 = difference of longitude of Zea, east of Melbourne.
provided the time was telegraphed accurately; whereas in all probability it was only telegraphed approximately.

	^{H.} 9	^{M.} 39	^{S.} 54.8	E.	or	^{O.} 144	['] 58	["] 32	E.
Longitude of Melbourne									
Difference as above . . .		1	24.0	"	"		21	0	"
Longitude of Zea . . .	9	41	18.8	"	"	145	19	32	"

APPENDIX V.

EXAMPLES ON CONVERGENCE OF MERIDIANS.

- (1) A geodetic line is run from Mount Dandenong, latitude $37^{\circ} 49' 45''$ S., longitude $145^{\circ} 21' 20''$, to a point A on the 145° meridian, with a bearing 270° from the north line at Dandenong (*Fig. 26.*) Determine the length of this line in feet, the latitude of A, and the angle that must be turned at A to arrive at the true meridian. Radius of curvature, perpendicular to meridian, for latitude $37^{\circ} 49' 45'' = 20,953,580$ feet. $AB = P \cos \phi = 1280 \cos 37^{\circ} 49' 45'' = 16' 51''$. Length of arc, radius 1, for $16' 51'' = .0049015$.



$$\text{Log } 0.0049015 = \bar{3}.6903290$$

$$,, \quad 20.953580 = 7.3212583$$

$$\hline 5.0115873 = \log 102704 = AB \text{ in feet.}$$

In triangle ABP, $PB = 90^{\circ} - 37^{\circ} 49' 45'' = 52^{\circ} 10' 15''$.

$$\angle APB = 145^{\circ} 21' 20'' - 145^{\circ} = 0^{\circ} 21' 20''. \quad \angle ABP = 90^{\circ}.$$

Required AP. Three circular parts ($90^{\circ} - AP$), ($90^{\circ} - 0^{\circ} 21' 20''$), ($52^{\circ} 10' 15''$).

$$\sin(90^\circ - 0^\circ 21' 20'') = \tan(90^\circ - AP) \tan 52^\circ 10' 15''.$$

$$\cos 0^\circ 21' 20'' = \tan \phi \tan 52^\circ 10' 15''.$$

$$\cos 0^\circ 21' 20''$$

$$\tan 52^\circ 10' 15'' = \tan \phi = \tan 37^\circ 49' 43'' = \text{latitude of point A, south.}$$

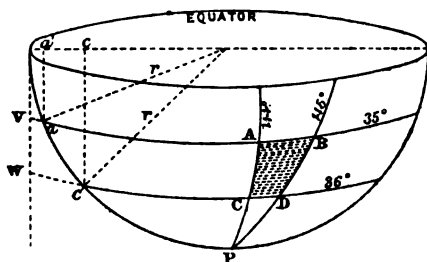
$$c = P \sin \phi = 1280 \sin 37^\circ 49' 43'' = 785'' = 13' 5'' = EAB - ABP$$

$$\text{but } \angle ABP = 90^\circ \therefore \angle EAB = 90^\circ + 13' 5'' = 90^\circ 13' 5'';$$

and hence $\angle PAB = 89^\circ 46' 55''$, the angle to be turned at A.

(2) Required the area in square feet of a geodetic block, bounded on the east and west by the 144th and 145th meridians, and on the north and south by the 35th and 36th parallels of latitude (Fig. 27). The earth to be assumed as a

Fig. 27.



sphere, radius 20,950,327 feet. This is a case where two of the boundaries are small circles, and, therefore, not sides of a spherical triangle, so it is necessary to use the spherical zone formula, area = $2\pi r \times \text{depth of zone}$.

Thus, area = $\frac{1}{360}$ area of zone between parallels 35° and 36°

$$= \frac{1}{360} \times 2\pi r (c' - ca') = \frac{2\pi r}{360} (r \sin 36^\circ - r \sin 35^\circ)$$

$$= \frac{2 \times 3.1415 \dots \times 20950327}{360} (20950327 \sin 36^\circ - 20950327 \sin 35^\circ)$$

$$= \frac{2 \times 3.1415 \dots \times 20950327}{360} (12314291 - 12016614)$$

$$= \frac{2 \times 3.1415 \dots \times 20950327 \times 297677}{360} = 108,848,450,000 \text{ square feet.}$$

The block shown in Fig. 19 is a block bounded by meridians and great circles; whereas the block in this example, Fig. 27, is bounded by meridians and parallels of latitude. Hence the difference in the method of solution.

(Paper No. 2571.)

“ Electric Lighting at Tamworth, New South Wales.

By EDMUND ROBERT DYMOND, Assoc. M. Inst. C.E.

TAMWORTH, New South Wales, is a town situated on the Northern Railway, about 258 miles N.E. of Sydney. The population is about 4,000, and the rateable value £33,700. As it was the first town in Australia to adopt electricity for street-lighting purposes, and as it offers a very fair example of what may be done in the future with regard to the lighting of small country towns, it is believed that a short description of the system employed, and of the results of working may prove of interest.

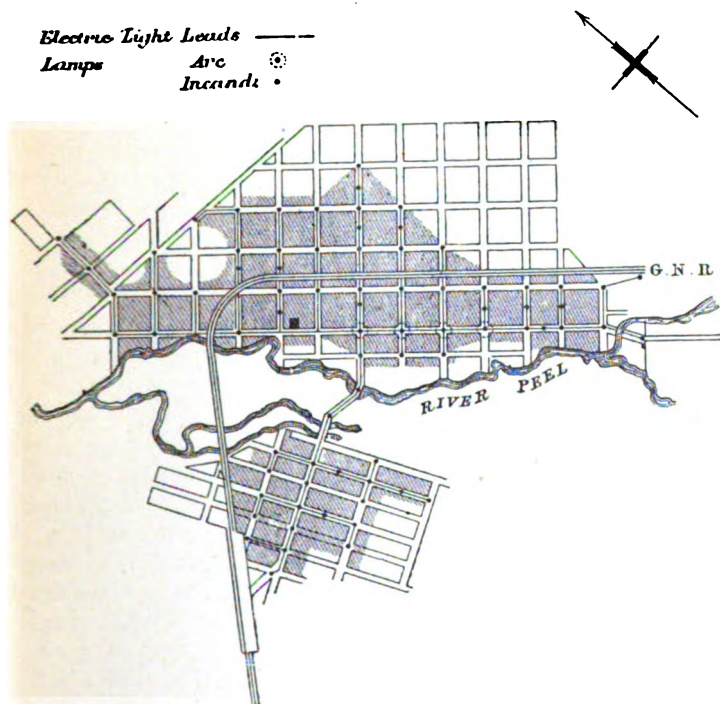
About the end of 1887, owing to some friction with the local gas-company, the town council decided to call for tenders, with the result that in November 1888, the gas was cut off from the street-lamps, since which time electricity has done duty in its place.

The electrical plant is duplicate throughout, both to reduce the risk of a breakdown, and also to provide for possible future extensions. The engines are compound, of 12-HP. (nominal) of the semi-fixed type, having the cylinders and motion placed underneath the boiler. They were supplied by Messrs. John Fowler and Co., of Leeds. The cranks are balanced, and have a central bearing placed between them. Both high- and low-pressure cylinders are fitted with expansion-valves, controlled by a Hartnell horizontal governor placed just over the guide-bars. The fire-boxes are enlarged to burn 3-foot logs. The usual working steam-pressure is 130 lbs. per square inch, and the revolutions 120 per minute. The engines are placed side by side in the station, and the steam-pipes are so arranged that either engine can be worked off either boiler. Each engine is fitted with a pump and injector. There is also an independent feed-pump, common to the two boilers.

Water is obtained from the River Peel, distant about 450 feet. It is raised to a tank at the rear of the engine-house by a pump driven off the line of counter-shafting. Formerly a steam-pump, erected on the river bank was used, but the loss through condensation in the steam-pipe to it was found to be excessive.

The two engines drive one countershaft, having a coupling in the centre of it, which can be thrown in or out of gear according to which engine or dynamo it is required to run. The dynamos, two in number, are by Messrs. Crompton and Co. They are compound wound, giving a current of 230 volts and 90 amperes, at a speed of 750 revolutions per minute. As in the case of the engines, only one dynamo is used at one time, the other being a

Fig. 1.

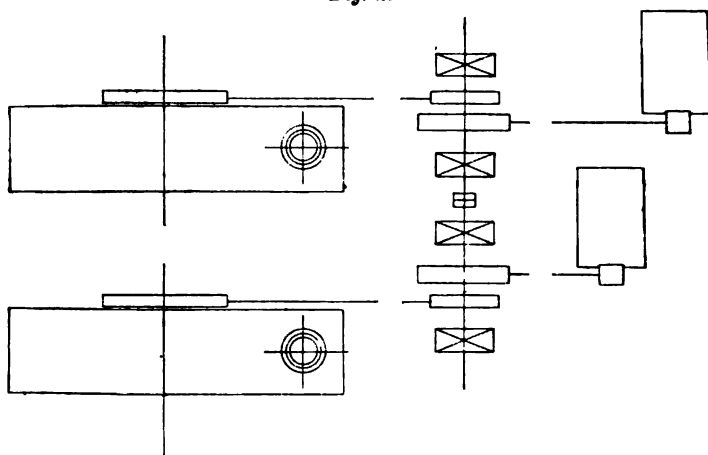


TAMWORTH, N.S.W., ELECTRIC LIGHT LEADS.

stand-by. There is also a spare armature provided, which can be used in either machine. The switchboard is a very simple one, carrying the main switches for the two dynamos, the usual main and branch cut-outs, and a double set of lightning-arresters.

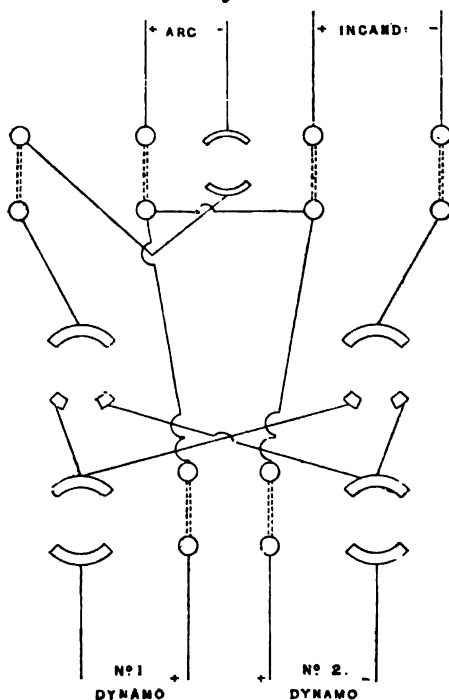
Fig. 1 is a map of the town, showing the position of the station, leads, and lamps. Fig. 2 is a plan of the engine-shed, and Fig. 3 is a tracing of the switchboard. The measuring

Fig. 2.



PLAN OF ENGINES AND DYNAMOS.

Fig. 3.



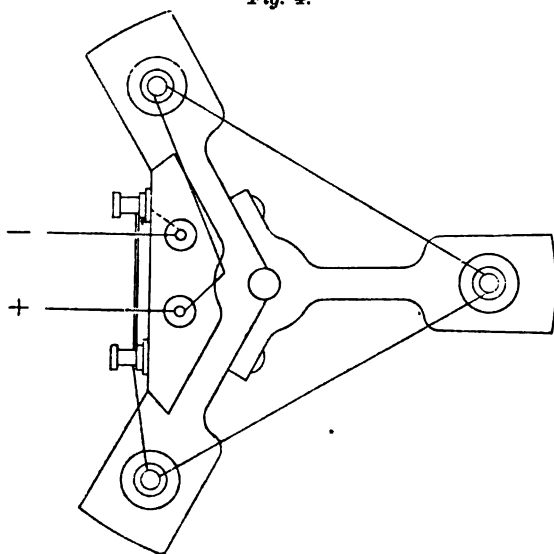
SWITCHBOARD.

instruments are not placed on the inside board, but on a table in the office.

The cables are throughout run overhead on poles 23 feet above the ground spaced 165 feet apart. The largest cable is 19-15 S. W. G., and the smallest No. 14. The smaller sizes are of hard drawn copper. All are but lightly insulated, the extreme heat and dryness of the climate rendering the use of india-rubber at once useless and unnecessary. The cables are strained up on shackles and insulators in the usual way, iron or steel suspending wires not being employed.

The lamps are placed in the existing gas lanterns, being fastened

Fig. 4.



LANTERN-ATTACHMENT.

to the central gas-pipe by a gun-metal clip (*Fig. 4*), which is, however, insulated from the gas-pipe by a fibre ring. Some lanterns have two lamps, and others three, according to their position. The glow-lamps are all of 16 candle-power, placed two in series, or three in some cases. In the main street there are also four arc-lamps of 3,000 nominal candle-power each. These are worked in series off a separate cable. The whole system is protected by cut-outs, those for branches being placed in a cast-iron box, bolted to the junction-pole, while a small fuse is fixed in every lantern. The total number of miles of streets now lighted

is thirteen and a half, the distance of the farthest lamp from the station being 2,100 yards. The maximum loss of pressure allowed is 10 per cent., but the average loss is not more than 5 per cent.

The lanterns nearest the station, and in the more important streets, have three 75-volt lamps in series. As the distance increases, two 110-volt, and lastly, two 105-volt lamps are used. The total number of lanterns now in use is eighty-six, besides the four arc-lamps in Peel Street mentioned before. The total number of 16-candle-power glow-lamps is one hundred and eighty-five. Taking into account the fact that the streets are all straight, and run parallel and at right-angles to each other, this number of lamps is quite sufficient to light the area covered.

As a nominal 32-candle illuminant now replaces one of a nominal 14-candle power, the streets are a good deal better lighted than formerly. The whole plant being most simple in design and arrangement offers a fair example for comparing the cost of street-lighting by gas and electricity in a small town in Australia.

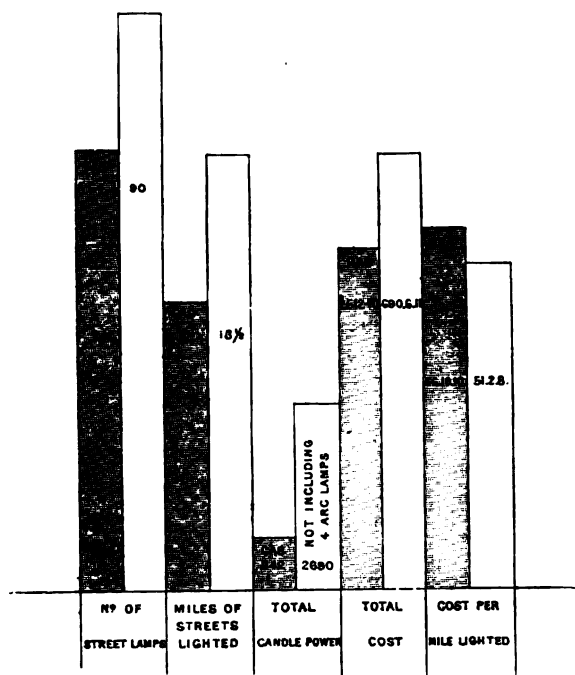
Formerly the town was lighted by fifty-five lanterns, each containing one 5-foot burner, and nine kerosene lamps, placed in certain isolated situations. The length of streets lighted was 9 miles, and the total candle-power of the whole was eight hundred and forty-two candles. The price of gas is (or was then) 10s. per 1,000 cubic feet. The council paid £8 2s. 6d. per year for each gas-lamp, and had to pay £10 a year for each of the oil-lamps, thus making the total yearly cost £512 10s. The total candle-power of the present system is 2,960 candles, not including the arc-lamps, and 14,160 with them.

As they, however, only light one street, it may be better to neglect them when comparing the former gas-lighting with the present plant. The total cost of lighting from November 1889 to November 1890, was £690 6s. 11d., made up of the following items.

	£	s.	d.	
Fuel	75	8	0	Wood at 8s. 6d. per ton.
Oil	12	19	9	[2 tons = about 1 ton of coal.]
Carbons	15	0	4	
Lamps	7	13	9	
Sundries and Repairs	18	9	1	
Electrician	163	16	0	£13 13s. per month.
Driver	130	0	0	£2 10s. per week.
Lamp-cleaner	12	0	0	
	435	6	11	
Interest	165	0	0	(5½ per cent. on £3,000)
Depreciation	90	0	0	(3 per cent. on £3,000.)
	£690	6	11	

As only one-half the plant is worked at one time, and as the cost of the generating plant forms the largest portion of the first cost, 3 per cent. on the whole capital value should be enough to fairly represent the yearly depreciation.

Fig. 5.



COMPARISON OF GAS AND ELECTRICITY AT TAMWORTH, N.S.W.,
Nov. 1889—Nov. 1890.

The following Table collects all the foregoing figures, and *Fig. 5* is a graphic representation of the same.

	No. of Lamps.	Miles of Streets Lighted.	Total Candle-Power.	Total Cost per Year.	Cost per Mile Lighted.
Gas	64	9	842	£ s. d. 512 10 0	£ s. d. 56 19 10
Electricity	90	13½	2,960 ¹	690 6 11	51 2 8

¹ Not including four arc-lamps of 3,000 candle-power each.

On comparing these figures it will be seen that although the present system costs more per year than the old, yet area for area, or effect for effect, the result is in favour of electricity. Formerly £56 19s. 10d. was paid per mile, which was lighted by about ninety-four candles, while now £51 2s. 8d. is paid per mile lighted by two hundred and nineteen candles. The council is at present debating the question of obtaining powers to supply private consumers. Should this be done, there is no question but that the cost of production per unit will be reduced, and with it the public lighting rate.

The hours of lighting are from sunset to two A.M.; but on four nights a month at full moon, the lamps are not lighted.

No accidents or breakdowns of any importance have been met with, the most serious one being due to lightning. The Tamworth district is very subject to violent thunderstorms, and on one occasion, notwithstanding the lightning-arresters, the insulation of one of the field-magnet coils was broken down and sparks passed between the coil and magnets. At another time, one of the cut-outs on the switchboard was fused during a thunderstorm, and a portion of the town was put in darkness for a few moments. It has been found that in thundery weather, very severe shocks can be obtained during the daytime from the lines, and it is necessary to first earth them before it is possible to handle them with comfort. The plant has now been at work for nearly three years, for the first of which it was maintained and run by the contractors at their own risk, payment being delayed until the end of the first year. Since that time it has been in the hands of the council.

The contract price of the installation was £3,000, which the council had to borrow at $5\frac{1}{2}$ per cent.

Of course, neither the figures nor the conclusions to be drawn from them will apply to English practice, where not only are the prices of material and labour different, but also legal questions and Board of Trade rules must be taken into account; but for the Australian colonies Tamworth affords a fair example of country town lighting, both as regards capacity, first cost, and working expenses.

The communication is accompanied by a series of drawings, from which the *Figs.* in the text have been prepared.

(Paper No. 2521.)

“The Southampton Waterworks and Softening Plant.”¹

By WILLIAM MATTHEWS, M. Inst. C.E.

THE wells and borings in the chalk, whence the present supply of water to Southampton is derived, have already been described by the Author.² The two wells referred to in his Paper have since been connected with about 400 feet of headings, 13 feet high and 4 feet wide, driven at a level of about 55 feet below the surface; and a supply of 3,000,000 gallons per day has been obtained. The average consumption during the past year has been 2,250,000 gallons per day; and this quantity is being further reduced by the use of Deacon's waste-water meters.

The Otterbourne Works, which form the subject of the present communication, consist of a pumping-station and softening-works (Plate 8, Fig. 1), situated on the west side of the London and South Western Railway, 1 mile south of Shawford station, and 8 miles from Southampton. Thirteen acres of land have been acquired; and the works are connected with the main road, from Southampton to Winchester, by a newly formed and fenced road, 980 yards long and 20 feet wide, and with the railway by means of a siding. A chalk pit has been opened out, and kilns erected for burning the lime used in the softening process, these and other portions of the works being connected by 2-foot gauge tramways, 475 yards in length. House accommodation is provided for the superintendent and six of the staff, who are required for night duties. A 24-inch pumping-main conveys the water from the works to a covered service-reservoir on Otterbourne Hill Common, $1\frac{1}{2}$ mile distant, and 160 feet above the level of the pumping station. Thence the water flows by gravity to Southampton, through $4\frac{1}{2}$ miles of 16-inch main as far as Swathling, where it is connected with a previously existing 24-inch main, leading from the now disused Mansbridge pumping station to the reservoirs on Southampton Common. Beyond

¹ This communication was received at the Institution on the 9th of February, 1891. In the number of *Engineering* for March 11, 1892, a description appeared of the Softening Plant at Southampton.—Sec. Inst. C.E.

² Minutes of Proceedings Inst. C.E., vol. xc. p. 35.

Swathling, a 16-inch branch main leads direct into the eastern portion of the borough, which is thus fed direct from Otterbourne. In case of need, however, the whole of the borough can be supplied from the Southampton reservoirs, which are 200 feet above Ordnance datum.

WATER-SOFTENING.

The Southampton Corporation, having determined to soften the water obtained from the new source, directed the Author to design the necessary works. Hitherto softening had been confined to supplies of under 1,000,000 gallons per day, the largest installation being that of the Colne Valley Water Company, at Bushey, where 900,000 gallons per day are treated; and the selection of a system capable of satisfactorily and economically dealing with 3,000,000 gallons per day was therefore attended with some anxiety. In June, 1884, when these works were planned, three different methods of softening were in actual operation, dealing with town supplies.

(a) The simple system of Dr. Clark, where the precipitated bicarbonate of lime, resulting from the admixture of the hard water and lime-water, subsides in large depositing tanks, from which, after a time, the clear softened water is drawn off.

(b) A modification of Dr. Clark's process, wherein, in lieu of depositing tanks, a system of filter-presses is used for the removal of the precipitated bicarbonate of lime. This system, the invention of Mr. J. H. Porter, Assoc. Inst. C.E., has recently been much improved; and the plant erected at Penarth Dock for working this process has been described by Mr. W. W. F. Pullen, Stud. Inst. C.E.¹

(c) A modification of Dr. Clark's process, in which a similar filtering medium to that used by Mr. Porter is adopted; but, in lieu of filter-presses, specially designed circular disks support the filter cloths in such a manner that they can be cleansed mechanically without removal. This system is the invention of Messrs. F. H. and W. G. Atkins.

By the courtesy of the Engineers and others connected with the waterworks where these systems have been adopted, the Author has been enabled to give, in Appendix I, many interesting particulars bearing upon this subject.

The method of softening invented by Mr. P. A. Maignen has not at present been applied to town supplies, although it is in

¹ Minutes of Proceedings Inst. C.E., vol. xcvi. p. 354.

successful use for treating the feed-water for boilers, and for other purposes. In this process, a specially prepared chemical "anti-calcaire" is automatically mixed with the hard water; and the resultant precipitate is induced to fall, and is arrested by means of variously arranged screens, baffle plates, and shelves which can be cleansed in a simple manner.

Another system is that of Messrs. Gaillet and Huet, which, with some modifications, is known as the "Stanhope softener," and has hitherto only been used for commercial purposes. Lime, and sometimes soda also, is mixed with the hard water, which then flows in an upward direction through tall tanks, fitted with inclined baffle plates and shelves, upon which the precipitated matter is deposited, and from which it can be readily removed.

The history and general principles of water-softening have been dealt with in a Paper by Mr. Baldwin Latham, M. Inst. C.E., read at the Health Congress in 1884.¹ The Author's investigations led to the adoption of the Atkins system of softening at Southampton, with results which have fully justified the selection. In first cost, there appeared to be little difference between the Atkins and Porter systems, the latter being slightly cheaper; while the cost of the simple Clark process would have been at least £3,000 greater, exclusive of land. The space occupied by the filtering-systems would have been very similar, and much less than that required by the large depositing-tanks used in the Clark system. The precipitated matter removed from the filters could, in either case, be run into waste pits conveniently placed for subsequent removal, or, where circumstances permitted, it could be run directly to "spoil." Where depositing tanks are used, the deposit must be dug out and removed, temporarily reducing the capacity of the plant by the disuse of one tank; or the tanks must be placed so high up that drainage from the bottom is possible, and even then a considerable expenditure of water is necessary to render the deposit sufficiently liquid to run through pipes; and such a plan usually involves the building of the tanks above ground at much additional cost. All the three systems admit of great regularity in the degree to which the water is softened, the method being simpler in cases where filters are employed.

As regards working-expenses, it is obvious that any system for dealing with large supplies must occupy the almost exclusive attention of at least one man. In the Clark system, lime has to be run into tanks, mixed with a certain quantity of water to form

¹ Journal of the Society of Arts, August 15, 1884.

lime-water of the proper strength, and then admitted, in a given proportion, together with the hard water, to the subsiding tanks, where, after an interval of some hours, it is in a sufficiently clear condition to be passed into the clear-water reservoir, and thence delivered to the high-lift pumps. Each of these operations involves the opening and closing of one or more valves, and would require the employment of one man by day, and another by night. In the Porter system, when once started, the apparatus works continuously and automatically until the deposit on the filtering medium requires removal, when the filter presses must be disengaged, and the frames removed by hand, cleansed, and replaced—operations involving a large amount of labour. This is avoided in the recent modified plant described by Mr. Pullen.

In the Atkins system, the filtering-medium can be cleansed *in situ* by mechanical means; and one man easily looks after the whole of the plant, and cleanses the filters, besides, when required, fitting new cloths to the filter-disks. From the Author's experience, an output of 5,000,000 gallons per twenty-four hours appears to be the maximum quantity with which one man could deal, when on duty for twelve hours; but if relieved after eight hours' work, he could attend to a plant dealing with 10,000,000 gallons per twenty-four hours.

One other point to be considered is equally in favour of the filtering systems. Where filters are adopted, the rate of flow cannot exceed the filtering capacity of the medium used; and if this is kept in proper condition, the water is certain to be delivered in a proper condition. On the contrary, where clarification depends upon subsidence, either in tanks or upon shelves and baffle plates, the satisfactory and complete removal of the precipitated matter depends upon there being a sufficient period of rest, or a sufficiently gentle flow through the depositing vessels; and should the demand for water outgrow the legitimate capacity of the plant, it is possible to hurry the subsiding operation, and pass imperfectly clarified water into the mains, causing trouble from blockage, and dissatisfaction to the consumers.

PUMPING-WORKS.

(Plate 8, Figs. 2 and 3; and Plate 9, Fig. 1.)

At the Otterbourne Works, pumping is effected by a pair of independent beam-engines, one working over each well. The cylinders are $28\frac{1}{2}$ inches in diameter, with a stroke of $4\frac{1}{2}$ feet; and $38\frac{1}{2}$ inches in diameter, with a stroke of 7 feet; the steam-receivers being formed

partly under the high-pressure cylinders, and partly in the bases of the low-pressure cylinders. The low-pressure valve-gear is of the Cornish type, fitted with pneumatic dash-pots, and worked by cams. The high-pressure valve-gear is of the Meyer expansion-slide type; the main valve is actuated from below, motion being taken from the shaft which drives the low-pressure cams, through a pair of spur-wheels, countershaft, and small crank; while the expansion-slide is actuated from above, motion being derived from the radius rod of the parallel motion. The rate of expansion is variable, the normal point being 0·3 of the stroke; whereas in the low-pressure cylinder, it is fixed at 0·5 of the stroke. The condensers are multitubular, the whole of the water passing through them, after softening, on its way to the high-lift pumps. The air-pumps are 22 inches in diameter, with a stroke of 2 feet 6½ inches. The beams are of cast-iron, 5 feet deep in the middle, and 23 feet 0½ inch between the extreme centres. The fly-wheels are 18 feet in diameter, with a sectional area of 63 inches at the rims, and have balance-weights cast in them. The crank shafts, connecting-rods, and pump rods, are of forged Yorkshire iron, the cranks having a stroke of 6 feet, and the connecting-rods being 20 feet long between the centres. The crank-pins and gudgeons are of steel.

There are two sets of pumps to each engine; the low-lift pumps, of which there is one hung down each well, are of the bucket-and-plunger type, driven direct from the beams; they have buckets of 1 foot 10 inches diameter and 5 feet stroke, with double valves of india-rubber working on grids and guards, and suction-valves of the same type and size. These pumps discharge, through a common annular air-vessel, into a 24-inch main, laid in a tunnel under the buildings, which conveys the water from the wells into the "mixer" of the softening plant. The high-lift pumps, driven direct from the outer beam centres, are designed to deliver 10 per cent. more than the low-lift pumps, as that quantity is added, in the form of lime-water, in the process of softening. The water, after softening, is delivered to these pumps through 36-inch pipes, tapering to 24 inches at the condensers, the pipes being of extra large size, so as to augment the somewhat small storage capacity of the softened-water tank. The pipes are extended beyond the pumps, and, provided with stand-pipes open at the top, raised to a somewhat higher level than the water stands in the softened-water tank, from which the supply is taken.

The pumps combine all the advantages of the bucket-and-plunger type. They are 19½ inches in diameter, with a stroke

of 7 feet; they have valves of the four-beat type, identical in form and size, with easy waterways, and deliver, through a common air-vessel, into the 24-inch rising main before-mentioned. Steam is supplied from three (two working) boilers, each 28 feet long and 7 feet in diameter, furnished with two flues, 2 feet 9 inches diameter, and four 8-inch to 4-inch Galloway cross tubes. The mild steel of which they are constructed was manufactured by the Butterley Iron Company, and had an average tensile breaking strain of 27·17 tons per square inch, with an elongation of 24·9 per cent. of the original length. Each engine, working at 18 revolutions per minute, delivers 2 million gallons of water per twenty-four hours, with a very low consumption of fuel. The slip of the pumps during the trials, from actual observation of the quantity delivered into the reservoir, amounted to 2·73 per cent. of the pump-displacement. (Appendix II.)

In a repairing-shop adjoining the boiler-house is a horizontal engine ($9\frac{1}{2}$ inches by 14 inches), with variable-expansion gear, which drives the machine-tools, and the machinery of the softening plant, besides acting, if required, as an auxiliary boiler feed. The pumping-engines, boilers, and tools were supplied and erected by Messrs. J. Simpson and Co.

SOFTENING-WORKS.

(Plate 8, Figs. 2 and 3; and Plate 9, Figs. 2 to 7.)

The lime required for softening is burned in two "flare burning" kilns, each yielding from 7 to $7\frac{1}{2}$ tons at each firing, this quantity being sufficient for a week's consumption. The kiln is drawn directly it is cool; and the lime conveyed to the mill house, where it is at once slaked. There are two slaking mills, which consist of cast-iron cylinders, 4 feet diameter and 3 feet high, fitted with perforated plates 3 inches above the bottom. A vertical shaft furnished with arms and fangs, revolves inside at a speed of 30 revolutions per minute, thus breaking up the lime; the power being derived from shafting fixed on the mill-house wall. Water from the service-main is laid on to each mill; and the cream of lime produced is run off, through full-way cocks, into a sieve and trough fixed between the mills, whence it falls into the lime storage tank. This tank, which is made of concrete lined with blue bricks, is 25 feet by $19\frac{1}{2}$ feet, and 7 feet deep at the centre, sloping in two directions to 5 feet at the sides. It is fitted with pipes, through which compressed air can be

discharged, so as to agitate the lime occasionally, and prevent its consolidation. The cream of lime is pumped up into the lime-water cylinders by a small pump fixed, together with the air-compressor, in one division of the mill house, and driven by the small engine in the repairing shop. The pipes connected with the lime pump, as well as all other pipes liable to become blocked up, are so fitted that water from the service main can be forced through them. The lime pump (5 inches by 6 inches) is single acting, and runs at 60 revolutions per minute. The air-compressor (6 inches by 8 inches) is double acting, and runs at 40 revolutions per minutes.

The two lime-water cylinders (Plate 9, Figs. 2 and 3) are fixed on brickwork piers in the lime house, partly above and partly below floor-level; they are open at the top, and are 9 feet in diameter, and 11 feet high in the cylindrical part, and below they have the form of a truncated cone. The plates are of mild steel, $\frac{1}{4}$ inch thick, single riveted, and strengthened with angle rings. A vertical shaft furnished with light stirring arms, makes 5 revolutions per minute in the coned portion of the cylinder, in order to agitate the lime—an operation which in practice is found to be scarcely necessary. The delivery pipes from the lime pump enter the cylinders 10½ feet below the top, through regulating valves, the introduction of cream of lime taking place every six hours, and occupying about fifteen minutes at each operation. Softened water from the service main is admitted, through self-acting ball-valves, into a small tank fixed over and between the cylinders, and is then discharged through 5-inch pipes also fitted with ball-valves, into the lowest portion of the cylinders. This water, flowing upwards through the cream of lime, forms lime-water, and, owing to the low velocity, due to the size of the cylinders, is drawn off from the upper part in a sufficiently clear state for use. Softened water is used in order to avoid the precipitation of bicarbonate of lime, which would necessitate a period of rest for subsidence; whereas the present arrangement permits of continuous working.

The lime-water is drawn off through a series of perforated collecting pipes placed horizontally in each cylinder, 18 inches below the top, and discharging into a 6-inch pipe, furnished with stop-valve and slow-motion graduated regulating-valve, which leads into the mixing-tank, where it comes into contact with the hard water from the well. A 6-inch waste valve is fixed in the bottom of each cylinder; and, by means of pipes, the waste lime is periodically discharged into pits placed conveniently outside

the buildings. Overflows also lead into these pipes. Space is reserved for the addition of two cylinders, and the necessary junctions; and floor-plate openings are arranged accordingly.

The mixing tank is open at the top, and is made of wrought-iron, $\frac{1}{4}$ inch thick, single riveted, and strengthened with angle-irons and flat stays; it is 3 feet deep, 15 feet long, semicircular at the end where the hard water enters, and 8 feet wide at the other end. The 24-inch main from the low-lift pumps enters through the bottom; and in order to assist the mixture of the hard water and the lime-water, the tank is fitted with a series of baffle plates.

A rectangular opening in the end allows the water to flow into the distributing trough; this is formed of $\frac{1}{4}$ -inch iron plates, single riveted, and strengthened with angle-irons and flat stays. It is 40 feet long, $2\frac{1}{2}$ feet deep at the back, 9 inches wide at the bottom, and $2\frac{1}{4}$ feet wide at the top. The front plate is inclined, and turned over outwards so as to form a lip, over which the water is discharged in a thin sheet, and, falling from 3 to 4 feet into the softening tank, ensures the perfect admixture of the hard water and lime-water.

The softening tank, covered with an iron and slated roof, is of concrete lined with blue bricks, the space of 2 inches between them being filled with strong cement compo, so as to be thoroughly watertight. It is 76 feet long, 44 feet 2 inches wide, 6 feet deep at one side, sloping to 7 feet at the other side, and furnished with two scouring channels leading, through valves and pipes, to the drains outside, which discharge into waste pits placed at the rear of the buildings at a lower level. Near the end of the tank adjacent to the filter house, a cross wall, $4\frac{3}{4}$ feet high, is built, so that the supply to the filters is taken from the upper surface of the water in the tank, by which means a certain quantity of deposit is arrested, and can be discharged into the waste pits, thus considerably easing the work of filtration. A weighted flap-valve, fixed in the wall, prevents undue pressure upon it when the tank is first charged. The water is about one hour passing through this tank, by which time the precipitation of bicarbonate of lime has ceased; and the water may safely be passed through the filters, without fear that further precipitation will occur in the pipes beyond.

There are thirteen filters, ten in one equally divided range at the back of the softening tank, whence they are fed direct, and three in an incomplete range facing them, and fed from a supply-tank placed in the repairing-shop, and supplied by an 18-inch

main laid from the softening tank under the filter-house floor (Plate 8, Figs. 2 and 3). There is thus space for seven additional filters, to complete the instalment; and the floor plates and pipes have been arranged so that they may be added in any number, at any time, without interfering with the existing plant. The supply-tank is formed of cast-iron flanged plates, $\frac{1}{2}$ inch thick; it is 18 feet long, 6 feet deep and 3 feet wide, and is furnished with loose cover-plates and scour-out. Water is admitted to the filters through horizontal 6-inch pipes, terminating, in the softening tank and supply tank, with bell-mouthed bends, in which heavy leather-faced valves are fitted, actuated from the front of the filters by levers and chains (Plate 9, Figs. 4, 5, and 6). Each filter consists of an open tank, cast in one piece, $\frac{3}{4}$ inch thick, $7\frac{1}{2}$ feet long, and 3 feet $7\frac{1}{2}$ inches wide; the ends are vertical, 6 feet deep on the centre line; while the bottom falls 3 inches each way towards the centre. The tank is U-shaped in cross section, having a radius of half the width. The inlet enters through the back plate, $9\frac{3}{4}$ inches above the bottom, where a socket is cast in the plate, and the joint made with lead. A 6-inch bend is bolted to an opening in the bottom of each tank, and discharges the waste, through a pipe and valve fixed under the floor, into a line of 12-inch pipes running the whole length of the house, and communicating with the drains outside. The valve is worked by a lever from above the floor-level. A cast-iron cross bearer is fixed across the back of the tank, and carries a brass-lined bearing fixed on the centre line, 4 feet $2\frac{1}{4}$ inches below the top; while a corresponding trunnion bearing is formed in the front plate of the tank. These serve to support the cast-iron disk shaft, which is $5\frac{1}{2}$ inches in diameter, and is hollow, closed at the back end, and has grooves and openings formed in it, so that the water from the disks which it carries may be admitted to the central portion. Near the front end, a spur-wheel is keyed on, and is driven by a pinion and short shaft, which works through a stuffing-box formed in the front plate of the tank, and is actuated on the outside by bevel gearing and shafting arranged along the front of the filters, and driven through belting from a line of shafting supported on the walls above them.

Each hollow shaft carries twenty galvanized cast-iron disks of light open-work pattern; they are 3 feet in diameter, and $\frac{7}{8}$ inch wide, and are covered on either side with perforated zinc sheeting, over which is stretched stout twilled cotton cloth, which acts as the filtering medium, the cloth being held in position by clip-rings and studs, which secure it at the periphery of the disk.

Galvanized cast-iron distance pieces are placed between the disks on the shaft, to keep them the requisite distance apart of $3\frac{1}{2}$ inches from centre to centre.

The turbid softened water, being admitted to the filters, percolates through the cloth into the disks, whence it passes to the hollow shaft, and through the trunnion to a valve fixed on the front of the filter, which regulates the flow into the softened-water tank formed under the filter-house floor. The water is now in a perfectly clear state, the precipitated bicarbonate of lime having been arrested on the face of the filter cloth, whence its removal is effected by means of water jets (Plate 9, Fig. 7). Between the disks, $\frac{3}{4}$ -inch spray pipes are placed, capped at their outer ends, and pierced on either side with small holes or slots. These pipes are connected by T-pieces to a $2\frac{1}{2}$ -inch pipe fixed along one side in each filter, closed at the back end, and mounted on a pivot; while the front end passes into a trunnion formed in the tank plate, and communicates with pipes and a regulating valve supplied from the high-pressure service main outside the building. The outer ends of the small spray pipes are fixed to a bar; and the whole set can thus be raised or lowered between the disks, the $2\frac{1}{2}$ -inch pipe being free to revolve in its bearings. The pipes are raised by a chain wound on a small drum, to which motion is given by worm gearing and a hand-wheel placed conveniently on the front of the filter.

The operation of cleansing a filter is as follows:—the inlet valve being closed, the water filters away, leaving the tank nearly empty; the outlet valve from the disk shaft is then closed, and the waste valve opened; next the disk shaft and disks are set revolving, and at the same time the spray valve is opened, and jets at high pressure are discharged from the spray pipes (Plate 9, Fig. 7). These being raised and lowered between the revolving disks, the whole surface of the cloth is swept by the spray, and the deposit washed off, and carried away through the waste pipes, leaving the filter again fit for use. With the thirteen filters working, the operation of cleansing, which occupies under two minutes, has to be repeated every seven or eight hours, when the plant is passing water at the rate of $2\frac{1}{2}$ million gallons in twenty-four hours. The outlet from the disk shaft is furnished with a by-pass leading into the waste pipes, so that by means of a valve fixed on the front of the filter, the water remaining in the shaft after cleansing may be run to waste, as it occasionally happens that a small amount of deposit is driven through the cloth by the force of the spray. This arrangement is, however, a refinement which might be

dispensed with. Originally each filter was provided with a 1-inch pipe and stop-cock, connecting the high-pressure service-pipes with the disk shaft, whereby water could be forced into the disks, and outwards through the cloth, with the idea of assisting to remove the deposit. But it was found that this distended and stretched the cloth beyond its elastic limit, so as to permanently open the interstices in such a manner that its value as a filtering medium was destroyed. The use of this "back flow" was therefore discontinued; but the pipes and fittings have been employed for occasionally blowing steam into the disks, which has the effect of thoroughly scouring the cloth, improving its filtering power and making it last longer. When thus treated for half an hour once a month, the cloths have a life of over eight months, filtering day and night continuously. Each disk-shaft is furnished with a locking and tightening bar, actuated by a screw and hand-wheel, so that, when released, the shaft and its appendages can revolve freely, but when tightened up is held firmly in place; and the trunnion joint, disks, and distance pieces are drawn closely together so as to make watertight joints. The disks revolve at 30 revolutions per minute; and the whole system is so arranged and furnished with loose pulleys, clutches, and friction gear, that the smallest possible amount of shafting is running at one time.

All the bright work on the filters and lime-cylinders is, so far as possible, nickel plated, as the great amount of condensation produced by the proximity of tanks containing water at a low temperature would otherwise render it almost impossible to keep the fittings free from rust. The soft-water tank into which the filters discharge is of concrete lined with blue bricks; it is $45\frac{1}{2}$ feet long, 11 feet wide, and $8\frac{3}{4}$ feet deep, except where it is above the tunnel; and here communication is established between the two sides by flat pipes. The filter-house floor is laid with cast-iron chequered plates, and is carried over the tank on rolled iron joists. From the tank, the water is led to the high-lift pumps through 36-inch pipes, as before described.

As the high-lift pumps deliver 10 per cent. more water than the well pumps, if a quantity of lime-water in excess of this difference is added to the well water, the flow into the soft-water tank will be in excess of the quantity drawn from it by the high-lift pumps, and an overflow will take place. On the other hand, if the added lime-water be less than 10 per cent., the pumps will gradually lower the water in the tank, and would eventually draw air, which is avoided by the introduction into the tank of a 3-inch branch from the service main outside, fitted with a ball-valve which only

acts to admit water when the water-level falls dangerously low. This compensating arrangement seldom comes into operation, as after a little experience the attendants are able to adjust the supply with very great regularity.

In order to be able to throw the softening-plant entirely out of work in case of accident, or for any other reason, a by-pass has been arranged, consisting of 24-inch pipes, forming a communication through valves, between the 24-inch delivery from the well pumps, where it passes under the repairing shop, and the 36-inch pipes leading to the high-lift pumps. The whole of the softening-plant was supplied by the Atkins Filter and Engineering Company, Mr. J. Cochrane of Barrhead being the manufacturer.

Analyses, made by Dr. Percy Frankland, B.Sc., of samples of the water taken during regular working, are given in Appendix III. It is possible, however, to further reduce the hardness to 3° or 4°; but the water has then a flat and insipid taste, and is not much appreciated in a non-manufacturing town such as Southampton.

The actual cost per annum of softening at these works, with an average output of 2½ million gallons per day, is as follows:—

	£
Lime, including all labour, fuel, and repairs to kilns . . .	379
Wages of attendants	156
Labour, cleaning out waste-pits and removing deposit . . .	151
Filter-cloth, 1½ sets per annum	56
Oil, stores, tools, and repairs	48
Steam-power (estimated)	53
	843

Cost per 1,000 gallons = 0·246d.

SERVICE-RESERVOIRS.

(Plate 9, Figs. 8, 9, and 10.)

The covered circular reservoir on Otterbourne Hill, 254 feet above Ordnance datum, built entirely below ground, is 150 feet in diameter, and when full has a water depth of 10½ feet, and a capacity of a million gallons. The outer wall is of concrete, 2½ feet thick, built against the excavated face of pebble beds overlying dry and sandy London Clay. The 12-inch concrete floor, together with the wall, was rendered and worked to a fine and almost polished surface, with such good effect that not a single crack has appeared; and the reservoir has proved absolutely watertight.

The roof is formed of five concentric rings of brick arching 9 inches thick, and a central dome, all covered with concrete, rendered over, tarred, and finished with a layer of soil and turf. It is supported by eighty-four brick piers (27 inches by 18 inches), with arches turned between them, and also by the wall of the central dome, and the outer concrete wall. The wall of the dome is pierced by three small arched openings; and a scour-out channel to facilitate cleansing is formed in the floor, and carried through the outer wall in a 12-inch cast-iron pipe, which is provided with a valve, and to which the overflow pipe is also connected. Access to the reservoir is gained by a flight of stone steps, leading from a dwarf entrance tower built of Portland stone in the Norman style of architecture. The valve chamber, which is built of concrete and brickwork, is independent of the reservoir; and from it the 16-inch delivery main is connected, by a 24-inch by-pass, to the rising main from the pumping works, before it enters the reservoir. A Silvertown electrical indicator records, at the pumping-station, the depth of water in the reservoir, the current being transmitted through a sheathed cable laid in the trench with the pumping main.

On Southampton Common, 200 feet above Ordnance datum, there are two open reservoirs, with rounded corners and sloping sides, which were constructed in 1852. They are placed side by side, with a bank, 11 feet wide at the top, between them; and they are 246 feet long by 156 feet wide at the water-line, and 210 feet by 120 feet at the bottom. When full, with a depth of 12 feet, they have a joint capacity of 5,000,000 gallons. They are lined with brickwork resting on concrete and puddle. The inflow of water from the 24-inch supply main from Swathling (Plate 8, Fig. 1) is controlled by an 18-inch stop-valve to each reservoir, which is also provided with an equilibrium float-valve. The outlets to the town, which are 18 inches in diameter, are furnished with screens, as are also the scour-out pipes. Both reservoirs are surrounded by a heavy cast-iron palisade and wire-netting to exclude dogs and other small animals.

MAINS AND FITTINGS.

The 24-inch and 16-inch mains are laid chiefly in 12-foot lengths with solid lead joints, no yarn being used. Sluice-valves (the 24-inch valves being geared) are placed at intervals of rather less than a mile; while reflux valves, air-valves, and scour-outs (from the bottom of the main pipe) are furnished where necessary,

and in convenient positions. The pipes, only two of which have failed, were supplied by Messrs. Cochrane, Grove and Co., and the fittings by Messrs. Guest and Chrimes. At two points, where the 16-inch main crosses the lines of the London and South Western Railway, the pipes are laid in subways, built in brickwork, and provided with manholes for inspection.

COST, WORKING EXPENSES, &c.

The cost of the new works has been as follows:—

	£
Experimental borings.	438
Wells, including lining	2,527
Headings	1,227
Pumping station and repairing shop	6,002
Engines, boilers, and machinery in ditto	12,483
Softening works, plant, and kilns	10,639
Otterbourne Hill reservoir, by-pass, and indicator	5,131
Mains and fittings	14,227
Roads, fencing, and tramways	837
Superintendent's house and six cottages	1,765
Railway siding, signal cabin, &c.	1,006
Alterations at Southampton reservoirs	570
Otterbourne village supply	251
Land, easements, and costs	5,360
Engineering and sundry expenses	2,500
Total	<u>64,963</u>

The total cost of water delivered in Southampton is as follows:—

	Per 1,000 gallons.
	d.
Pumping (lift = 218 feet).	0·544
Softening	0·246
Distribution	0·297
Management.	0·276
Rates and taxes.	0·077
Total	<u>1·440</u>

	£
Cost of water per annum	4,926
Less receipts from meters (£2,705) = 6d. per 1,000 gallons, and sundry items (£129)	<u>2,834</u>
	<u>2,092</u>

which sum is covered by a water-rate of 2d. in the pound upon

the rateable value of the properties supplied, the present rateable value of the borough being £262,366.

	£
The total sum which has been raised on capital account for purposes of water-supply to the borough is . . .	202,588
Amount paid off	76,053
Balance	126,535

The annual charge for interest (£5,184), and repayment of capital (£3,113), amounting to £8,297, is met as a portion of the general district sanitary rate, which is thus augmented by 8*d.* in the pound, making the total cost for water 10*d.* in the pound upon the rateable value of the premises, or 3·866*d.* per 1,000 gallons.

In conclusion, the Author desires to testify to the ability and services, during the construction of the new works, of Mr. E. T. Hildred, Assoc. M. Inst. C.E., who was Resident Engineer at the time of their completion; and also to acknowledge the assistance rendered by Mr. J. Blackburn, Assoc. M. Inst. C.E., of the Colne Valley Waterworks, who placed the results of his experience in water-softening at the Author's disposal.

The Paper is illustrated by a map and tracings, from which Plates 8 and 9 have been compiled.

APPEN

APPENDIX I.—PARTICULARS OF SOFTENING-WORKS

Name of proprietors	East Surrey Company. ¹	Canterbury Company. ²	Colne Valley Company.
Situation of works	Caterham and Kenley.	Canterbury.	Bushey.
Date when inaugurated	1861	1869	1876
Name of Engineer	S. C. Homersham.	S. C. Homersham.	J. F. Bateman.
Name of Resident Engineer or manager	J. Burlinson.	T. Buckley.	J. Blackburn.
System of softening	Clark.	Clark.	Clark.
Ultimate capacity of works, gallons per twenty-four hours	750,000	1,000,000	2,000,000
Cost	(not stated.)	(not stated.)	(not stated.)
Ultimate capacity per £1 expended on works	..	..	..
Space occupied by works (square yards)	1,100	1,216	5,200
Ultimate capacity per square yard occupied gallons	682	822	385
Average quantity actually softened per twenty-four hours gallons	500,000	400,000	900,000
Cost of softening 1,000 gallons . pence	1·00 (?)	0·33	0·296
Hardness of water { before softening	24	17	18½
{ after	3½	3½	4
{ removed by „	20½	13½	14½

Softening plants are also in operation at the following places among others :—

Clark system	{ Herbert Hospital, Woolwich. Chiltern Hills Co., Tring.
Porter system	{ Willesden, Camden Town. Liverpool, and other stations on the L. and N. W. Railway. Bow Works, N. L. Railway. Mirfield, L. and Y. Railway.
Atkins system	{ Brighton Works, L. B. and S. C. Railway. Prudential Assurance Co.'s Offices. Darenth Asylum. Leavesden Schools.

¹ Royal Commission on Water-Supply, 1869.

² "Water-Supply of Cities and Towns," W. Humber, p. 283.

DIXES.

IN OPERATION AT VARIOUS PLACES.

South Hants Company.	Henley Company. ³	Wellingboro' Local Board.	Southampton Corporation.	Taff Vale Railway Company. ⁴	Saffron Walden Corporation.	Stroud (Gloucester) Company.
Mottisfont.	Henley.	Wellingboro'.	Otterbourne.	Penarth Dock.	Saffron Walden.	Stroud.
1879	1882	1886	1888	1889	1890	1890
Russ and Minna.	Jabez Church.	E. Sharman.	W. Matthews.	T. H. Riches.	Jabez Church.	C. Minna.
G. Greenelade.	J. Dawes.	E. Sharman.	W. Matthews.	T. H. Riches.	J. Wilson.	G. Scriven.
Clark.	Atkins.	Atkins.	Atkins.	Porter.	Atkins.	Clark.
480,000	480,000	600,000	3,000,000	120,000	240,000	750,000
£3,250	£2,450	£3,500	£10,640	£1,100	£2,800	£5,500
148	196	171	235	110	86	136
2,100	780	400	1,150	90	191	1,670
230	615	1,500	2,600	1,330	1,256	450
360,000	180,000	166,000	2,250,000	120,000	80,000	300,000
0·31	0·34	0·79	0·246	0·63	{ (not ascertained.) }	0·75
18	21½	37	18	18	25	17
8	5	13	6	6	13	5
10	16½	24	12	12	12	12
		(Highly impregnated with iron before softening.)				

Stanhope system { Hull Waterworks (Boilers).
 Messrs. Garton, Hill & Co.'s Sugar Works, Wandsworth.
 Mr. J. Duncan, Sugar Works, Victoria Dock, London.
 Messrs. J. Smith and Sons, Woollen Works, Bradford.

Maignen system { Southwark and Vauxhall Waterworks (Boilers).
 Nine Elms Works, L. and S. W. Railway.
 Bournemouth Waterworks (Boilers).
 Oxford Waterworks (Boilers).
 Messrs. Tangye's Works, Birmingham.

³ *Engineer*, vol. lv., p. 4.

⁴ Minutes of Proceedings Inst. C.E., vol. xcvii. p. 334.

APPENDIX II.—ENGINE-TRIALS.

Date.	Engine.	Duration of Trial.	Revolutions.		Steam.	Vacuum.	Barome cr.	Head of Water.		Coal Consumed.	
			Total.	Per Minute.				High-Lift.	Low-Lift.	Total.	Per Hour.
Nov. 1, 1888	A.	Hours. 10½	10,850	17·22	Lbs. 60·6	Inches. 28·50	Inches. 29·72	Feet. 159·73	Feet. 58·90	Lbs. 1,757	Lbs. 168
" 9, "	B.	10½	11,060	17·55	60·0	28·46	29·80	161·15	57·70	1,750	167

Date.	Engine.	Ashes.	Water Lifted.		H.P.		Mechanical Efficiency of Engines.	Coal Consumed.		Duty, Millions.
			High-Lift.	Low-Lift.	Actual.	Indicated.		Per Indicated HP.	Per Actual HP.	
Nov. 1, 1888	A.	Lbs. 14	Gallons. 955,125	Gallons. 868,651	98·00	115·55	Per Cent. 84·81	Lbs. per Hour. 1·454	Lbs. per Hour. 1·714	129·3
" 9, "	B.	15	973,612	885,464	100·02	117·93	84·80	1·416	1·670	132·8

APPENDIX III.—ANALYSES.

	Well Water. Parts in 100,000.	Softened Water. Parts in 100,000.
<i>General Analysis.</i>		
Total solid matters	31·69	14·07
Organic carbon	0·024	0·021
„ nitrogen	0·012	0·013
Ammonia	0·005	0·004
Nitrogen, as nitrates and nitrites	0·365	0·381
Total combined nitrogen	0·381	0·397
Chlorine	1·6	1·6
<i>Mineral Analysis.</i>		
Silica (SiO ₂)	1·02	0·94
Oxide of iron and alumina {Fe ₂ O ₃ Al ₂ O ₃ }	0·14	0·11
Lime (CaO)	14·53	4·42
Magnesia (MgO)	0·25	0·28
Soda (Na ₂ O)	1·21	1·12
Sulphuric acid (SO ₃)	0·39	0·45
Nitric acid (N ₂ O ₅)	1·41	1·47
Chlorine (Cl)	1·60	1·60
Carbonic acid (CO ₂), from carbonates of lime and mag- nesia	10·64	2·64
	31·19	13·03
Less Oxygen—equivalent of chlorine	0·36	0·36
Total solid residue	30·83	12·67
Carbonate of lime (CaCO ₃)	23·93	5·67
„ magnesia (MgCO ₃)	0·21	0·29
Hardness {	Degrees.	Degrees.
	16·10	3·92
	1·89	2·10
Total	17·99	6·02

(*Paper No. 2565.*)

"The Hawarden Bridge."

By FRANCIS FOX, M. Inst. C.E.

OWING to the physical conformation of the estuary of the River Dee, the swing portion of the Hawarden bridge over it was required to be the largest opening span in the kingdom, namely, 140 feet clear opening, as compared with Leith docks, 120 feet; Tyne bridge, two spans of 110 feet; Ouse bridge (N. E. R.), two spans of 100 feet; and Ouse bridge (Hull and Barnsley Railway), two spans of 100 feet.

The width of the estuary, from the Point of Air to Hilbre Island, is 5 miles; whereas, at Connah's Quay, the available width of the river is only 430 yards; and, at the site of the bridge, it is only 150 yards, owing to the land having been reclaimed, and the river canalized. Consequently the flood-tide is preceded by a "bore," sometimes 3 to 4 feet in height, its size depending upon the height of the tide, and the direction and force of the wind. The tide on the flood attains its full height in two hours; it remains stationary for about twenty minutes, and then ebbs for about ten hours, falling at first even more quickly than it rises. The velocity of the bore during spring-tides is about 7 knots per hour, and for the first half hour of the flood-tide, the stream attains a speed of 4 to 5 knots per hour; whereas the ebbing tide runs out at only 2 knots per hour, on the average. The tide comes in loaded with sand, which it carries into the upper reaches of the river; and during the time of high water, this is quietly deposited, and the ebbing water runs out nearly clear. The continual silting thus occasioned, keeps the river very shallow; and it is only during the flood of spring-tides that vessels of any size can ascend to Saltney and Chester. These vessels, the largest of which is about 350 tons, pass the site of the bridge with a velocity of 8 to 10 knots per hour. They are generally attached in pairs, or in fours, two abreast, to a steam-tug; and consequently the Board of Trade, advised by Sir George S. Nares, K.C.B., R.N., decided that the proposed bridge should have one navigable opening of 140 feet. The Act of Parliament for the bridge was obtained in 1886, by the

Manchester, Sheffield, and Lincolnshire Railway Company; the Author being shortly afterwards appointed Chief Engineer, both for this work, and for the connecting railway from Chester to the bridge.

The bridge consists of two fixed spans of 120 feet each, and of one swing portion, 287 feet in length over all, which gives two unequal openings, the largest of which, being for the navigation, is 140 feet clear span; whilst the tail-end of the girder gives a clear span of 87 feet (Plate 10, Figs. 1 and 2). The bridge carries a double line of railway, with a footpath, 4 feet in width, supported on cantilevers outside the main girders. The first cylinder was pitched in the presence of the Right Hon. W. E. Gladstone, M.P., Sir Edward W. Watkin, Bart., M.P., the Chairman, and other directors of the company, on August 16th, 1887. The completed bridge was opened by Mrs. Gladstone, who named it the "Hawarden Bridge," on August 3rd, 1889, when a train of saloon and dining cars travelled from King's Cross to Chester, and thence over the new railway and the bridge for the first time.

Piers and Abutments.—The "Sands of Dee" having an unenviable notoriety, much careful consideration was devoted to the question of foundations. It was decided to adopt again, as already described by the Author,¹ the Indian system of brick wells, although the diameter of 40 feet, required for the centre turntable, was large for this system. Difficulties having arisen in other swing-bridges, in consequence of the centre race and pivot having been placed on a group of cylinders which settled unequally, it was decided to have only one cylinder, sufficiently large to take the central race. A wrought-iron caisson was provided, having a cutting ring, 43 feet in diameter, consisting of $\frac{1}{2}$ -inch plates riveted together, with a special rolled section of iron, forming the actual cutting edge, inserted between them (Plate 10, Fig. 3). These plates rise vertically for a height of 9 feet outside; but, internally, they slope upwards towards the centre of the cylinder, until, at a height of 9 feet above the bottom edge, they are reduced to a diameter of 30 feet. This gives the shoe of the cylinder the necessary form for sinking, and provides an annular space, 5 feet wide, between the two skins of the caisson, which was filled with cement concrete made 5 to 1. To avoid the expense and delay of tide work, and in consequence of the impossibility of making an artificial island, as in the case of Indian bridges, the iron plating was brought up 24 feet, sufficiently high to reach

¹ Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 304.

above high-water mark when the cylinder was lowered on the bed of the river. Directly this operation was completed, the annular space was filled with about 200 tons of concrete; and a circular wall of brindle bricks in cement, 5 feet thick, and having an internal diameter of 30 feet, was carried well up above the water-level. Dredging with a grab was then commenced inside the cylinder; and as the material was removed, the cylinder gradually sank, and the brick walls were raised in height. During these operations, an exceptionally heavy bore came up the river before the cylinder was more than 5 feet in the river bed, causing it to tilt on one side to a considerable extent; but such perfect control over the movement of the cylinder was retained by the regulation of the "grabbing," and by the pumping of water under the cutting edge, that this tilting was utilized to keep the cylinder in true line, both longitudinally and crosswise. Although the weight of the mass was 2,300 tons, it could be adjusted to a nicety, and when finished, was within half an inch of its true position. The weight on the cutting edge of the cylinder, at the commencement of the sinking, was about 6 tons per lineal foot, which was increased by the addition of the brickwork as the cylinder descended. When the cylinder had reached the requisite depth of 48 feet below the bed of the river, the bottom was levelled by the grab, or by a diver when necessary, and was concreted under water, by means of "pigeon-trap" boxes, to a depth of 18 feet, with strong concrete in cement; so as to withstand the hydrostatic pressure. As soon as this concrete had set, sealing the bottom of the cylinder, the water was pumped out; and the remaining height was concreted in the dry (Plate 10, Fig. 3). At the height of 17.50 feet above Ordnance datum, or 18 inches above high-water mark, a floor of brickwork in cement was laid over the whole surface. The masonry for the race, and the block of granite, 9 feet square by 3 feet thick, for the central pivot, were then fixed (Plate 10, Fig. 4). The same system was adopted for most of the other cylinders, although they were of smaller diameter, and would have been for all, had the diameter, in all cases, been sufficient to allow the grab to pass down inside the brick wells.

The Cheshire abutment and No. 3 pier each consists of two brick cylinders, 12 feet to 10 feet, and 14 feet to 12 feet diameter, united together above the water-level by an arch of brickwork in cement. No. 2 pier has three brick cylinders, 14 feet to 12 feet in diameter, connected by brick arches, on which are fixed the masonry and bed-plates for receiving the fore end of the swing girder (Plate 10, Figs. 5 and 6). The cylinders for the tail race,

being only 8 feet to 6 feet in diameter, are of cast-iron, and, after being sunk by grabbing, were concreted, and capped with brick-work. The cylinders were weighted with a test load of 50 per cent. more than the permanent load, without movement.

Fenders.—A large timber fender protects the swing girder from vessels passing through the bridge; and the piles for this were sunk by aid of water-jets, a system inaugurated by Sir James Brunlees, Past-President Inst. C.E.,¹ many years since, and subsequently employed at the Calais harbour works,² but not often adopted (Plate 10, Fig. 2). The piles are cut off square, thus offering a flat surface for the weight to rest upon. A 2-inch pipe is temporarily spiked on to the side of the pile, which is then pitched in its place; this pipe is connected by a flexible hose to a steam-pump, and water being pumped through it, is discharged immediately beneath the pile, thus rendering the sand "quick"; and so long as pumping is continued, the pile sinks as quickly or as slowly as desired. As soon as the required depth is reached, and before the pumping is stopped, the pile is easily drawn into proper line, or rotated until square to the walings; and so accurately can the piles be sunk by this system, that all the bolt-holes are bored through the piles before they are pitched. When it is finally in proper position, the pumping is stopped; and the 2-inch pipe is drawn from the pile, and used again for the next. By this system, a pile can be sunk 20 to 25 feet in sand in two minutes, without the delay, uncertainty, or damage which so frequently accompany the ordinary system of pile-driving. Sometimes a nodule of clay, or erratic boulder of the glacial drift is encountered by the pile; but by sinking another pipe down to the level of the underside of the stone or nodule, and pumping, the obstruction sinks away in advance of the pile which rapidly follows. Within half an hour of the pumping being stopped, the sand settles round the pile, and no amount of ordinary pile-driving will stir it a fraction of an inch.

The same system of "washing-down" was employed under the cutting edge of the 40-foot cylinder; and this system is capable of various applications in connection with the sinking of foundations. By providing for jets of water round the cutting edge of cylinders, and at intervals up the entire height of the caisson, the process of sinking is greatly facilitated and accelerated, the skin friction being reduced to almost any desired extent.

¹ Minutes of Proceedings Inst C.E., vol. xvii. p. 444; and vol. xx. p. 294.

² *Ibid.*, vol. liii. p. 312.

Swing-Bridge.—This portion of the bridge consists of two main girders, constructed of mild steel, each having a total length of $284\frac{3}{4}$ feet, and a total depth at the pivot of 32 feet, and $9\frac{1}{2}$ feet at the ends (Plate 10, Figs. 1, 2, and 3). The pivot is $116\frac{1}{2}$ feet from the tail-end, and $168\frac{1}{4}$ feet from the fore end of the girder. The girders are $27\frac{1}{2}$ feet apart, centre to centre; and the clear width inside is 25 feet 2 inches. The girders are lattice, divided into panels, 17 feet wide, with single, triangulated, vertical and diagonal members, except over the pivot where the members cross each other. The top booms are curved and bow-shaped, and the bottom booms are horizontal. The sections of the various members are of the simplest form, the connections being made by junction plates and rivets; and smith's work was avoided wherever possible. The bottom booms are of a square trough section, and the top booms are the same, but inverted. The lattice members are of I girder section, made of plates and angle-irons, and are, therefore, capable of resisting compressive strains, which is important, as the strains alternate with the opening and closing of the bridge, and with the passing of the load. This system, together with an efficient method of cross bracing, has, it is believed, prevented the girders from becoming distorted, which, if it took place in consequence of changes in temperature or other cause, would render the fitting of the bridge difficult. No trouble in this respect has been experienced; and the girders have exhibited a highly satisfactory rigidity and stiffness.

The permanent way is carried upon cross girders, 28 inches deep over the angle-irons, and 17 feet apart, fixed to the bottom boom of the main girders, and in line with their vertical members, to which the cross girders are also attached by a peculiarly shaped gusset or corner bracket. The latter, in addition to its primary object, carries a very convenient platelayers footway, and also supports the rail guard required by the Board of Trade. The rails are borne on ordinary chairs, fixed upon longitudinal timbers, 16 inches by 5 inches, which are carried by steel-plate girders, or rail-bearers, $22\frac{1}{4}$ inches in depth, whose ends are fastened to the webs of the cross girders. The rail-bearers are stiffened, and tied together, and to the main girders, by steel tee-bars at intervals of $4\frac{1}{2}$ feet. The latter also form bearers for the floor, which consists of bars, $\frac{1}{2}$ inch thick, with spaces between to prevent accumulation of ashes or snow, and to permit the wind and rain to pass through. The component parts of each member were made in one piece without joint, so as to reduce the dead weight as much as possible, which, combined with the economical pitch and depths of the cross

girders and rail-bearers, has produced a very light and strong platform. The weight per square foot is 38 lbs., including the corner brackets and gangway plates, but exclusive of the permanent way. In building the main girders, the manufacturers were instructed to set them out and erect them without camber; and the bottom booms were accordingly laid and fixed level. The deflection which would ensue when the longer end of the girder is unsupported, was calculated; and provision was made in the lifting apparatus at the tail-end, to take out this amount of deflection, and bring the girder back to its normal level, and thus free it, as much as possible, from stresses due to its own weight, when in position to carry the railway traffic.

Bascule Movement.—The swing span, in addition to its rotatory motion, is arranged with a slight bascule movement, for the purpose of lifting the fore ends of the main girders out of their bearing sockets. This movement is effected by lowering the tail-end, which is made to preponderate to the extent of about 15 tons, partly by means of the balance weight, and partly by the weight of the tail rollers, &c. The drop at the tail-end is 8 inches, which, if the girder was not elastic, should cause a corresponding elevation at the fore end of $11\frac{1}{2}$ inches. The rise of the fore end from the bedplate is actually 8 inches on the average, the difference of the two dimensions being the deflection of the girder, namely $3\frac{1}{2}$ inches.

Lifting-Apparatus at Tail-End.—The lifting-apparatus at the tail-end, consisting of a pair of vertical single-acting hydraulic rams, 25 inches in diameter and $8\frac{3}{4}$ inches stroke, one fixed under the end of each main girder on the Cheshire abutment, has not only to lift the 15 tons preponderance, but also the much greater load due to the resistance of the girders to being straightened. This is slight at first, but rapidly increases until a maximum of 269 tons is reached, as ascertained by experiment. The rams have a total lifting-power of 300 tons.

Pivot Cross-bearing Girder.—With the exception of the small preponderating portion of the balance above referred to, the entire weight of the swing span and balance, amounting to about 732 tons, (see Appendix), is carried by the pivot cross-bearing girder, the weight being equally disposed at each extremity and transmitted to the centre (Plate 10, Figs. 7, 8, 9, and 10). The girder, 30 feet long, is divided into four equal sections, $6\frac{1}{2}$ feet in depth, and 1 foot $4\frac{1}{2}$ inches in width. The girder is suspended at the centre by two large steel bolts, $10\frac{3}{4}$ feet long, with a minimum diameter of 9 inches, and having special screwed ends and nuts, by which the whole

weight of the swing span can be raised and lowered for adjustment (Plate 10, Figs. 12 and 13). The bolts are suspended at each end of a steel crosshead ($8\frac{3}{4}$ feet $\times$ $2\frac{1}{2}$ feet $\times$ $1\frac{1}{2}$ foot), $5\frac{3}{4}$ tons in weight, which rests upon the pivot. The crosshead passes over the bearing girder, the top of which is level with the deck of the bridge; and it is therefore visible in the 6-foot way, and, together with the upper ends of the suspension bolts, is accessible therefrom. By this arrangement all adjustments can be effected, and the pivot can be readily examined, or entirely removed and replaced, without interfering with the railway traffic. This, moreover, raises the level of the pivot, which is thus brought as near as possible to the centre of gravity of the moving girder. By dividing the bearing girder into four parts, the pillar which carries the pivot passes up between the two centre portions, and the bolts descend between the two outer sections, thus distributing the weight equally amongst the several members.

Crosshead and Suspending Bolts.—The bolts and crosshead are made of hammered cast-steel, and every precaution was taken to ensure their soundness; and after being machined and finished, they were tested with a strain of 1,000 tons (Plate 10, Figs. 12 and 13). The working load on the couple is 732 tons, and the estimated breaking load is 3,500 tons. The threads of the bolts are of the saw-tooth pattern; the bearing surfaces are horizontal, and therefore no bursting strain or wedge action is exercised on the nuts; and large bearing areas are provided on the threads. The nuts have been screwed on and off many times, with the entire load upon them, and the threads remain quite perfect. In the remote contingency of the bolts and crosshead failing, the entire load would descend upon the steadying rollers, which are capable of carrying the bridge round independently of the pivot. If these again were to fail, the bridge would descend 1 inch and rest upon the parapet of the main pier, which is a solid ring of brickwork and ironwork, 40 feet in diameter.

Pivot.—A solid bearing-pivot was adopted in preference to a hydraulic ram, or water bearing, as, the necessary vertical movement of the bridge having been provided for, a ram was not required. Moreover, several disasters have occurred in connection with water bearings in this country and abroad; and leakage is also liable to occur. The form adopted is a cup and ball, 30 inches in diameter, each part being made of forged wrought-iron, and the wearing surfaces case-hardened; and it provides for both the rotatory and bascule movements of the bridge (Plate 10, Figs. 9 and 12). The weight on the pivot, when the bridge is being opened, is 732 tons,

which would be equal to a load of 1 ton per square inch of bearing surface, if the entire surfaces were in contact; but as the radius of the cup is a quarter of an inch larger than that of the ball, which is $19\frac{1}{2}$ inches, the weight per square inch is very much greater at the centre. The bearing "seized" at first, and caused a humming noise whilst the span was being turned; but it was found that the contact of the ball in the cup was in small, irregular patches, probably on account of distortion due to the case-hardening which was performed after the surfaces had been machined. On being restored, and a lubricant forced in from below by means of a small hand-pump, the pivot worked perfectly well, and has done so ever since. As it wears down, the bearing area will increase; no signs of wear have, however, yet been observed. The lubricant used is heavy cylinder oil, heated to make it fluid; and it is injected on an average once for every three times the bridge is opened, the consumption of oil being about $\frac{1}{2}$ gallon per week. The bridge is opened about eleven times per week.

Rotatory Rams.—The two rams for opening and closing the bridge are fixed upon massive cast-iron bedplates built into, and bolted down to the solid brickwork of the main pier (Plate 10, Figs. 3 and 4). They are laid horizontally, and parallel to the longitudinal axis of the bridge, at a distance of 18 feet on each side of the pivot. Both rams are single-acting, and are geared with chains in the proportion of 2 to 1; and one ram opens, and the other closes the bridge. One end of each chain is fixed to the head of each cylinder; the chain then passes over a sheave, 4 feet in diameter, fixed upon the head of the ram; and the other end is attached to a large drum or sheave, 32 feet in diameter, which forms part of the main bearing girder. The rams are thus in direct connection with the swing span, and also with one another; and they therefore act in unison, one coming in as the other goes out. A screw adjustment is provided at the cylinder end of each chain, by which the movement of the bridge can be regulated to a nicety. The rams are placed close up to their work; and the chains are of the shortest possible length. The rams are 19 inches in diameter, and 151 inches stroke net; and the cylinders have a clearance of 4 inches beyond this. The stroke is sufficient to open the bridge through an arc of 90° . The chains are pin and link, and are made of steel. The pins, which are $2\frac{1}{4}$ inches in diameter by $6\frac{1}{2}$ inches pitch, are accurately turned; and the holes in the links are bored. The links have a total sectional area of $7\frac{1}{2}$ square inches.

Retarding Gear.—Fixed upon the top of each cylinder, and

automatically worked by the movement of the rams, is a water brake, designed by Mr. Frank Pearn for the purpose of gradually starting and arresting the movement of the bridge. The man in charge may open the starting valve full bore, and leave it so after the arc of rotation has been completed; but by means of this apparatus, the movement is beautifully controlled, the great mass is put into motion slowly, its speed increases, and at the end of its travel is arrested without the smallest vibration or tremor. This is effected by admitting the supply through a hollow tubular piston, in which are about sixty holes, $\frac{1}{8}$ inch in diameter, only a few of which admit the water to the cylinder at the beginning of the stroke, whilst the remainder are gradually uncovered as the travel proceeds. The action is reversed in the opposite cylinder, the exhaust being throttled to bring the span to a standstill. The thought at once suggests itself that the effect of this must be to increase considerably the pressure inside the cylinder which is being exhausted, towards the end of the stroke. Experiments, indeed, have shown that the maximum pressure attained is 900 lbs., the normal pressure being 700 lbs., which the parts are well able to bear. The rams, pivot, &c., are protected from the weather by a house, the flat roof of which is immediately below the underside of the main girders of the swing span. The interior is warmed by steam pipes from the boiler house, and thus a suitable temperature is maintained in cold or frosty weather.

Steading Rollers.—Four rollers of cast-steel, 3 feet in diameter, are provided, two under each end of the main bearing girder, and directly under the main girders on the pivot pier (Plate 10, Figs. 9, 10, and 11). The rollers revolve in a wrought-iron carriage, upon fixed radial axles, which are centred to, and turn round the base of the pivot pillar. The rollers travel upon a cast-steel track arranged in two quadrants, $13\frac{3}{4}$ feet radius, fixed to the solid brickwork of the pier. Each axle has two bearings, one inside and one outside the roller; and above each bearing is a pair of long steel wedges, by means of which the weight can be either entirely removed from the rollers, or increased so as to take the total load of the bridge, in the event of the load being removed from the suspension bolts. In practice, however, the total vertical load is carried by the bolts; and the rollers take only the lateral pressure caused by the action of the wind upon the main girders. The wedges are driven in tight by a sledge hammer, to prevent any oscillating movement. The weight is disposed on the roller carriage, exactly on the transverse axis of the bridge, by means of a knuckle-shaped cast-iron saddle placed upon the top of the carriage, in a central position between the

rollers; and the bascule movement, although scarcely perceptible, is thus provided for. The arrangement works exceedingly well, all adjustments can be made to a nicety, and all tendency to rock under a high wind is prevented.

Tail Rollers and Hand Gear.—Two cast-steel rollers, 3 feet in diameter, are placed at the tail-end of the main girders, one under each girder, which carry the preponderating load only, which is about 15 tons. They are fixed in frames attached to the outer side of each girder, and travel upon a cast-steel track, having a radius of 115 feet, through an arc of 90°. Each roller is fitted with a winch gear and brake, in order that the bridge may be opened and closed by hand, in the unlikely contingency of the hydraulic gear getting out of order. The track is carried upon wrought-iron box girders, fixed upon cast-iron cylinders filled with concrete, placed about 38 feet apart. The interior of the box girders is utilized for conveying the hydraulic pipes between the engine-house on the Cheshire bank and the pivot pier. The pipes are thus out of sight, and protected from the weather, though easy of access.

Mechanical Locking.—When the bridge is being closed, the bascule movement is utilized, not only to bring the span into true line, but also to lock it securely in position. The lifting rams raise the tail-end of the span, which is provided with a tapered projection entering into a corresponding slot fixed to the abutment; and at the same time the fore ends of the main girders fall into cast-iron bedplates with tapered sides. When this has taken place, solid cast-iron bearing blocks are inserted underneath the girders at the tail-end. These blocks are also given a slight taper on the sides, and fit into corresponding bedplates attached to the girders above them and the abutment below. The top and bottom faces of the blocks are parallel to each other, as no lifting movement is required of them. The rams lift the tail about an eighth of an inch higher than the normal level, in order that the blocks may enter freely. These blocks are moved by a hand wheel and gear, similar to a steering wheel, placed in the tower. Provision is made for working this gear by hydraulic power; but it was thought desirable at the outset, that this final, essential operation, of mechanically fixing the bridge, should have a more sensitive connection with the man in charge than hydraulic power can afford. If anything went wrong with the apparatus, which is out of his sight, the blocks would not enter, and he would immediately feel it, which would not be the case if he simply had to turn a tap. An index on the wheel shows him when they are home; assuring him that everything is in perfect order, and that

the bridge is in absolutely true line and level. It is his interest to see that the blocks are kept clean and well oiled.

Automatic Closing of Rails and Foot-Bridge.—The bascule movement is again utilized for automatically closing the space, which would otherwise occur, between the ends of the rails on the moving and fixed portions of the bridge. An apparatus at each end, as the bridge closes, causes the rails to move forward until they meet, thus enabling trains to go over at full speed. The same movement automatically closes a gate on the footpath, thus preventing persons walking into the river when the bridge is open.

Motive Power.—The motive power is situated in a building on the Cheshire bank of the river, alongside the railway, and close to the tail-end of the swing span; and both the steam and hydraulic plant are in duplicate. There are two steam boilers of 12 HP. each, and one of 25 HP., of semi-portable multitubular type, and having a working pressure of 70 lbs. The two vertical double-acting steam-pumps, built by Messrs. Frank Pearn & Co., have each a pair of cylinders 12 inches in diameter and 10 inches stroke, a pair of rams $3\frac{3}{4}$ inches diameter, and a pair of balance rams $2\frac{5}{8}$ inches in diameter. The two accumulators have each rams of $20\frac{1}{2}$ inches diameter and 14 feet stroke, weighted with 92 tons of cast-iron cylinder weights to give a pressure of 700 lbs. per square inch. The capacity of each accumulator is sufficient to open and close the bridge once without replenishing; and each pump is able to raise an accumulator to the top of its stroke in ten minutes. Both the pumps and accumulators are provided with automatic starting- and stopping-gear. In case of an accident to a pipe, causing the water to escape with undue rapidity, the accumulator is provided with a throttling arrangement which would prevent it falling with any dangerous speed. The accumulators are placed in a tower, on the upper floor of which the man in charge stands, and has a good view of the bridge, the river, and the railway, and where all the hydraulic pipes are led to a controlling valve, a compact apparatus made of gun metal. The pressure not being excessive, and the water used being clean, a slide valve was adopted, which simplifies the working parts, and reduces the number of levers, so that only two are required, one for opening, and one for closing the bridge. The pressure and exhaust pipes are of steel, $2\frac{1}{4}$ inches in diameter and $\frac{1}{4}$ inch thick. The flanges are cast-iron, and are jointed with four bolts each; and the joint is made perfectly watertight with copper washers.

Electric Locking.—All the important moving parts of the bridge are electrically interlocked with the signals, so that until every-

thing is exactly in its place, and the bridge ready for traffic, the signals, not only at the bridge, but also at the stations on both sides, cannot be lowered.

Opening of Bridge.—In order to open the bridge, permission has first to be obtained from the signal boxes, which can only be given when all the signals are at danger. This permission releases the key lever in the bridge tower, the movement of which backlocks the signals at the boxes. The operations are then as follows:—(1) Lifting the tail-end of the bridge $\frac{1}{2}$ inch by the tail-end rams; (2) Withdrawing the sliding bearing blocks from under the tail end; (3) Lowering the tail-end rollers; and (4) Setting in motion the rotating rams. The proper sequence of these operations is secured by electrical contacts placed in different parts of the bridge, so that no fresh movement can be made until the preceding one is completed. Without this provision, there might have been the dangerous possibility, at night time, of the rotating rams being set in motion before the bridge was lowered on to its race. The time occupied in opening the bridge, from the moment of the first intimation that a vessel has to pass through till the bridge is full open, is two and a half minutes.

Steel in Girders.—The steel in the girders is calculated to carry, under its greatest load, a strain of $6\frac{1}{2}$ tons in tension and 5 tons in compression. The steel was made by the Steel Company of Scotland, and gave remarkably uniform results, the average being 31 tons per square inch breaking strain, 49·30 per cent. elongation in 10 inches, and 22·36 per cent. contraction of area.

Inspection and Test-Load.—The bridge was inspected, on behalf of the Board of Trade, by Lieut.-General Hutchinson, R.E. The test-load consisted of six of the heaviest locomotives and tenders, weighing altogether 427 tons. The greatest deflection on the swing span was 0·72 inch. In his report, Lieut.-General Hutchinson says:—"The whole of the work connected with this important bridge being, so far as I can judge, of a thoroughly satisfactory and substantial character, I have no hesitation in recommending the Board of Trade to sanction its being brought into use."

Signalling.—The signalling of the bridge was carried out by Messrs. Mackenzie and Holland, of Worcester, the electrical interlocking being done by Mr. Sykes. The telegraph masts, erected by Messrs. Mackenzie and Holland, are 164 feet high from ground line to pinnacle, and 177 feet from foundation plate to summit. They are 2 feet 6 inches square at ground line, and are built of lattice ironwork.

Cost.—The total cost of the bridge, including all extras and duplicate parts, was £71,000, equivalent to £128·85 per lineal foot.

The contractors for the whole work were Messrs. John Cochrane and Sons, of Westminster, who were ably represented on the spot by Mr. A. H. Cochrane. The sub-contractors for the superstructure, and the hydraulic machinery, were the Horseley Company, of Tipton, Staffordshire. The details of the bridge were in great measure designed by Mr. G. A. Hobson, M. Inst. C.E.; and the Author was represented on the works by the resident engineer, Mr. S. B. Cottrell, Assoc. M. Inst. C.E.

The communication was accompanied by photographs and working drawings, from which Plate 10 has been prepared.

APPENDIX.

WEIGHT OF SWING SPAN AND MOVING PARTS.

	Tons.	Cwts.	Qrs.	Lbs.	Tons.	Cwts.	Qrs.	Lbs.
Main girders, cross girders, rail bearers, floor bearers, wind bracing, and webs of footway brackets (steel)	442	9	2	13				
Floor plates, bars and angles, rail guard angles (wrought-iron)	46	6	0	5				
Tees and angles in footway brackets (wrought-iron)	8	14	2	6				
Outside footway brackets and standards	3	10	0	0				
Hand-rail tubes and fastenings	1	6	3	19				
					502	7	0	15
Rails, fish-plates, fastenings, chairs, way beams, and guard timbers	..	..	..	..	49	8	0	0
Balance weight, 113 tons 16 cwts., less 8 tons 16 cwts. preponderance	..	..	..	..	105	0	0	0
Weight of swing span complete					656	15	0	15
Bearing girder	37	1	0	3				
Chain sheave, 32 ft. diameter	7	6	3	0				
Steel crosshead	5	13	2	0				
Steel suspension bolts and nuts	3	5	2	0				
Cast-iron washers and caps for suspension bolts	3	2	2	0				
Steel chains, one half of total weight	1	14	1	0				
Pivot ball	0	13	0	0				
					58	16	2	3
Total weight on pivot					715	11	2	18
Steel rollers at pivot	4	6	1	0				
Wrought-iron carriages for steel rollers	3	19	2	0				
Cast-iron knuckle plates and saddles	1	8	2	0				
Wrought-iron ring with radial axles	0	16	1	0				
Steel chains, one-half of total weight	1	14	1	0				
Tail rollers and winch gear complete	3	11	2	0				
Balance weight, preponderance only	8	16	0	0				
Cast-iron bed plates at tail-end	1	4	0	0				
Locking gear at tail-end	1	10	0	0				
					27	6	1	0
Rams and sheave, say	..	..	..	..	10	0	0	0
Total weight of moving parts					752	17	3	18

(Paper No. 2601.)

“The Arauco Railway and Bio-Bio Bridge.”

By EDWARD JOHN THEODORE MANBY, M. Inst. C.E.

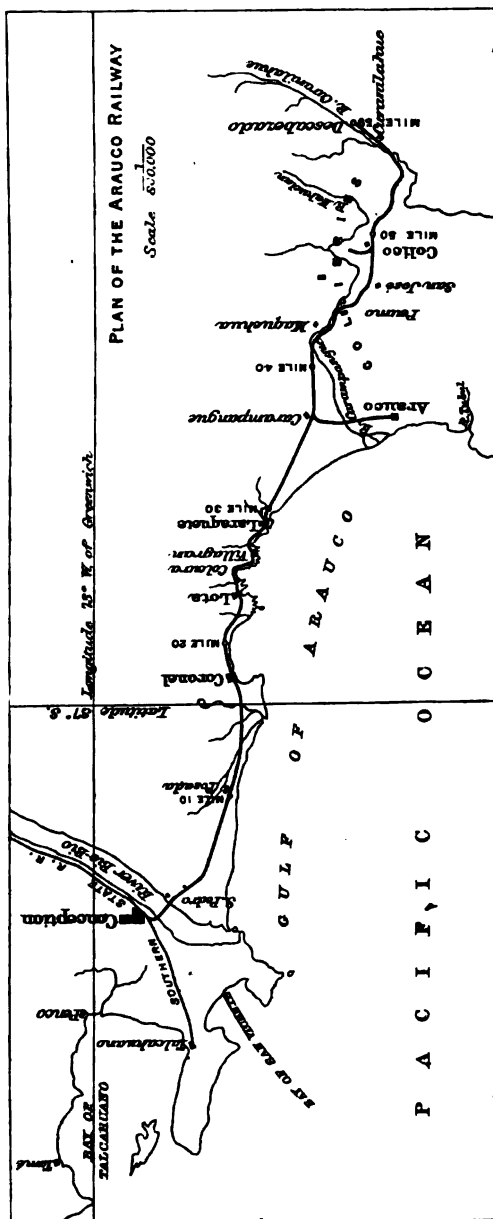
THE Arauco Railway is situated in the south of Chili, in the provinces of Concepcion and Lebu. From its junction with the State Railway in the city of Concepcion it follows a southerly direction along the sea coast for 30 miles; then, turning inland, it runs through the Arauco Company's coal properties, and ends at a spot called Descabezado, 59 miles from Concepcion (*Fig. 1*).

The construction of the railway was commenced in November 1886, and the main line was opened to traffic throughout on the 1st of April 1890. A branch line, 5 miles long, has since been built from mile 37 on the main line to the city of Arauco, and was inaugurated in April 1891.

The main object of the construction of this railway was the development of the Arauco Company's coal properties, which extend from mile 41 to some distance beyond the present end of the line at mile 59. The staple article of transport is of course the company's coal, but there is besides a considerable amount of general goods and passenger traffic. Almost immediately after leaving Concepcion, the line meets the River Bio-Bio, which it crosses by means of an iron bridge 6,118 feet long, a full description of which will be given further on. After crossing the river, the line runs over easy ground to the port of Coronel (mile $17\frac{1}{2}$), and afterwards through some rough country to Lota, mile 23. From Lota to Laraquete (mile 30) the line follows the face of very steep cliffs, where exceedingly heavy work occurs. This section includes nine tunnels and many very deep cuttings. From Laraquete to the end of the main line the earthworks are tolerably heavy, and numerous timber bridges and viaducts occur, some of which are 60 feet high.

The Arauco Railway is built to the standard gauge of the Chilean State railways, 1 metre 68 centimetres, equal to 5 feet 6 $\frac{1}{2}$ inches. The width at formation-level is generally about 15 feet. The rails

Fig. 1.



are of the Vignoles pattern, and weigh 50 lbs. to the yard. The sleepers are of native timber. The limiting radius of curve is 660 feet. The maximum gradient is about 1 in 90, but there is no great length of it, and the line is generally very easy, with long stretches of level and gradients under 1 in 150. The rocks traversed south of the Bio-Bio river are almost exclusively micaceous schist, clay, and sandstone, belonging to the coal formation. The schist is hard, and contains numerous quartz veins. To the north of the river the formation changes, and the tunnel forming the northern approach to the Bio-Bio bridge runs through gneiss. All these rocks disintegrate rapidly by exposure to the atmosphere, and the tunnels require, therefore, to be lined throughout. The only iron bridges are the Bio-Bio bridge and another of a single 81 feet span near Laraquete. All the remaining bridges are of timber, the piles or trestles being of native timber, and the stringers of Oregon pine. The usual type of trestle bridge consists of 20 feet spans, with four longitudinals 16 inches by 12 inches of Oregon pine. The native timber makes excellent pillars, but it is not so reliable under tensile strain. It is generally of a very enduring nature.

The total number of tunnels is twelve, and their aggregate length 2,300 yards, out of which 720 yards were driven by means of compressed-air machinery, and the remaining 1,580 yards by hand. All these tunnels gave a good deal of trouble, owing to the treacherous nature of the rock. Their cost, including lining over nine-tenths of their total length, has been £44 5s. 2d. per lineal yard. The lining is generally of brick in the arch and stone in the walling, but in some places of either material throughout. The thickness varies from 18 inches to 24 inches, and 3 feet in bad places.

The rolling-stock is of English manufacture; it is built with central couplings, which are used on all the Chilian State railways. The locomotives are of four different types, weighing 16, 20, 35, and 42 tons respectively. The three heavier types are six-wheel coupled engines. Their rigid wheel-base does not exceed 9 feet. The passenger carriages are of the American type, on bogie trucks. The coal-wagons are four-wheeled, weighing about 5 tons, and carrying 10 to 11 tons of coal. Recently some American tubular frame bogie-cars have been sent out, weighing about 9 tons, and intended to carry 24 tons.

The total cost of the Arauco Railway, 64 miles in length, including the branch line to Arauco city, has been £571,900, distributed as follows:—

	£
Earthworks	119,200
Tunnels	101,800
Bio-Bio bridge, including general expenses	74,500
Other bridges and culverts	18,000
Permanent way	58,100
Buildings	46,900
Land and expropriation	13,100
Fencing	4,400
Telegraph	900
Rolling stock	47,900
General expenses, comprising freights, insurance, commissions, agencies, landing-charges, carriage, general expenses, salaries, house-expenses, law-costs, surveys and preliminary expenses for all parts of the railway except the Bio-Bio Bridge	87,100
Total	<u>£571,900</u>

Or £8,936 per mile.

THE BIO-BIO BRIDGE.

The Bio-Bio river, which flows past the city of Concepcion, is the widest on the west coast of South America. It is also one of the shallowest during the greater part of the year, as the average depth of lowest summer water does not exceed 18 inches. But it rises very rapidly when the rainy season begins, and attains, in exceptional years, a maximum height of 9 feet above summer water-level. It rains very heavily in this part of Chili; the annual rainfall is generally between 50 and 60 inches. In 1883 it amounted to 65 inches, of which 53 inches fell in five months, from May to October. The bed of the river is composed of heavy, coarse, black sand, reaching to a very great depth. Borings made for coal-prospecting in the banks not far from the site of the bridge have gone through 150 feet of sand before touching rock, and it is probable that the depth in the river valley is still greater. The borings for the bridge were not carried down beyond 50 feet, because it was ascertained that the sand possessed the requisite bearing-power at a much lesser depth. This body of sand is intersected at varying depths by beds of clay and gravel, generally not more than a few inches, but in some places as much as 2 feet in thickness. The average speed of the current is generally from 3 to 3½ miles per hour, but during freshets attains 6 to 6½ miles. The deepest channels are constantly varying in position. The greatest depth of scour is about 12 feet below the level of summer water-level. The mouth of the river is only

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about 5 miles below the site of the bridge; but the effect of the tides at the bridge is barely perceptible.

The preliminary borings and experiments led to the following conclusions :—

I. That at a depth of less than 20 feet the bearing-power of the sand was at least equal to $7\frac{1}{2}$ tons per square foot, which was the greatest load that could conveniently be placed upon the experimental piles.

II. That screw-piles penetrated this sand with extreme difficulty, and that blades of the required diameter could not be expected, with ordinary means, to reach a greater depth than 12 or 14 feet, which was hardly sufficient for safety against scour.

III. That, judging from the great facility with which some experimental disk-piles were driven to a depth of 28 feet into the sand by means of a small hydraulic jet, there was every probability of reaching that depth with disks of 3 feet, and even 3 feet 6 inches in diameter, by using more powerful appliances.

The system of concrete piers in wrought-iron cylinders, sunk by machine diggers, was at one time suggested; but, apart from the many obvious uncertainties attached to this process under the circumstances, it was principally feared that it might prove a very slow one. The period available for construction was very short, and it was considered that the system of foundation most likely to combine rapidity of construction with the necessary bearing-surface and penetration would be the disk-footed piles invented by Sir James Brunlees, Past President Inst. C.E., sunk by means of the hydraulic jet. The clear waterway between piers was, after some discussion with the Chilean Government, fixed at 82 feet (25 metres), and upon this leading dimension the bridge was designed. The bridge is 6,118 feet long, or 1.16 mile. It consists of sixty-two spans of "Warren riveted" girders (similar in shape to some designed by Sir Alexander Rendel, K.C.I.E., for the Indian State narrow-gauge railways), of 81 feet 8 inches clear opening, resting on sixty-one piers of cast-iron disk-piles, and a brick abutment at each end. Each pier is composed of six piles, divided into two rows of three, 15 feet apart between centres along line of bridge, the three piles in each row being 6 feet apart from centre to centre. These piles are connected by longitudinal and transverse bracing, and each row bears a stout box-girder, on which the ends of the longitudinal girders are supported. The longitudinal girders are 6 feet apart between centre lines. The short longitudinal girders which rest over the piers are fixed at both ends to the cross-bearing box-girders. The main girders

are fixed at one end, and rest on rollers at the other. The top boom of each girder carries a balk of timber, upon which are bolted cross sleepers, 2 feet apart between centres. Upon these are spiked the rails and guard-rails. The gauge being 5 feet 6½ inches, the centre of the rail falls well over the longitudinal timbers. The two middle piles of each pier are 15 inches in outer diameter and 1½ inch thick. Their disk-feet are 3 feet 6 inches in diameter. The four outer piles are 12 inches outer diameter and 1 inch thick, with disks 3 feet in diameter. The maximum possible pressure at the foot of the disks, under a train of the heaviest locomotives, amounts to 4·93 tons per square foot on the middle piles, and 3·38 tons on the outer ones. The tested bearing-power of the sand at much less depth than the disks have reached was 7·75 tons per square foot.

The normal level of the bottom of the disk-feet is 55 feet 3 inches below rail-level, and about 28 feet 6 inches below the average level of the river-bed. A good many disks, especially the 3-foot 6-inch ones, have not reached this depth, but all are many feet below the level of possible scour. The highest flood-level ever known to have been reached by the Bio-Bio river is 6 feet 6 inches below the bottom of the longitudinal girders of the bridge.

The weights of the ironwork in the bridge are as follows :—

<i>Piers.</i>		
Cast-iron piles, packing-plates and bolts	1,235	Tons.
Wrought-iron bracing	230	Tons.
	—1,465	
<i>Superstructure.</i>		
Cross-bearing girders	89	
Roller-boxes and rollers	42	
Longitudinal pier-girders	205	
Longitudinal main girders	1,485	
Handrailing	67	
	—1,888	
Total	3,353	

The weight of each pair of longitudinal main girders with their bracing is therefore 23 tons 19 cwt. The total weight of iron in the superstructure is 30 tons 9 cwt. per span. The average weight of iron in a pier is 23 tons 16 cwt. 2 qrs.

PILE-SINKING.

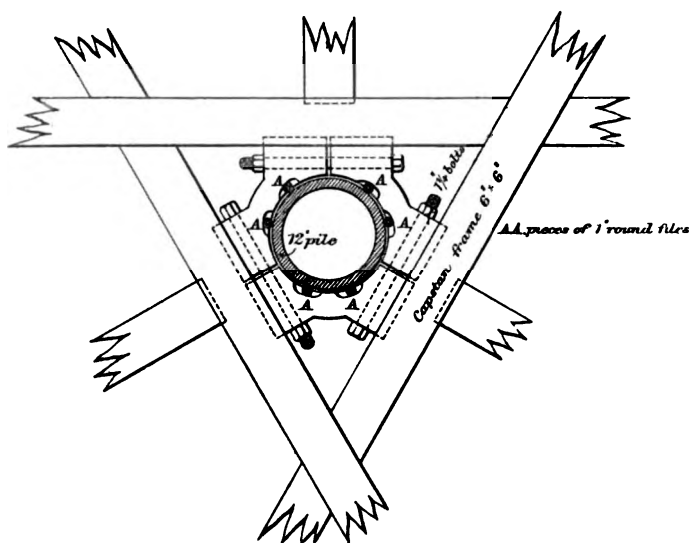
The disk-feet of the piles were of the well-known shape illustrated in Fig. A, Plate 13, vol. xxvii. of the Minutes of Proceedings of this Institution. They were put down by the water-jet system described in the same volume, and were rotated by steam-power. The pumping-machinery on the southern bank of the river consisted of two Tangye pumps delivering into a 5-inch main, from which the water was taken through 3-inch hose to 3-inch wrought-iron pipes running down the centre of the cast-iron piles, and discharging generally about 8 inches below the disk. The water delivered amounted to about 10,000 gallons per hour, and was sufficient to sink two piles at a time. On the northern bank a duplex Worthington pump was used, capable of delivering about the same quantity.

The piles were rotated by means of steam-winches having double cylinders, 7 inches by 12 inches stroke, fed from semi-portable boilers of from 16 to 18 HP., working at 80 to 90 lbs. pressure. These winches drove, from a 15-inch drum, an endless wire rope $2\frac{1}{2}$ -inch circumference which wound several times round a capstan 8 feet in diameter fixed on the cast-iron pile. The arms and frame of the capstan were of timber bolted on to a cast-iron collar or grip, made in three segments. Each of these segments had two wedge-shaped recesses, into which were dropped pieces of 1-inch round files. (Fig. 2); when the pull came on the capstan, these got jammed between the pile and the narrowing wall of the recess, and served to grip the pile very firmly. This form of grip answered very well, and seldom slipped. When the pile was very wet, a spadeful of sand thrown into the recesses would stop any slipping at once. Yet the strain at the periphery of the pile was sometimes enormous when a pile was driving through stiff ground, and a sudden jerk would come from the winch. Under such circumstances the $2\frac{1}{2}$ -inch wire rope frequently parted, and on two occasions the eight 1-inch bolts connecting two of the 12-inch pile lengths, were sheared through by a sudden pull. The lower part of all columns driven to the normal depth, consisted of the disk-foot, section 2 feet 6 inches high, and three 10-foot lengths. This lower part was driven down until the top flange of the uppermost 10-foot length remained 2 feet 6 inches above an assumed line of level of average summer waters, in those piers where the ends of the main girders rested on rollers, and 2 feet $11\frac{1}{2}$ inches above the same level in those piers where the ends of

the main girders were fixed directly to the cross bearing girders. From the lower portion, the columns were continued upwards by an intermediate length, normally 5 feet 9 inches long, and a capital length 5 feet long, upon which the transverse bearing girders were bolted.

The steam-winches and boilers, after the first four piers were driven from the shore, were always established on timber frames bolted to the lower parts of the six columns of a driven pier, and, from that position, served to drive four piers ahead without

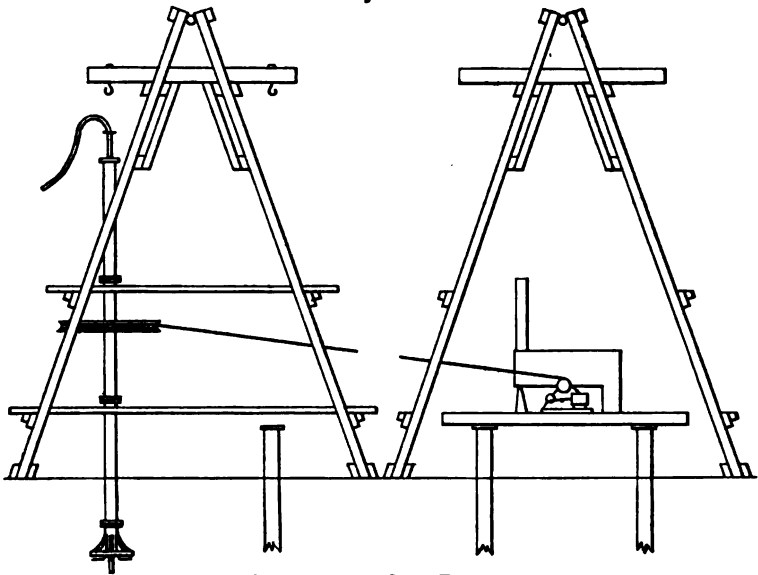
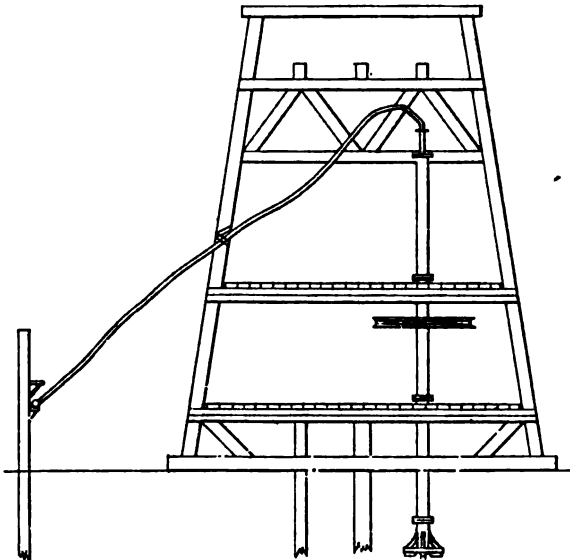
Fig. 2.



GRIP FOR PILE-DRIVING.

Scale $\frac{1}{4}$ inch = 1 foot.

shifting by means of varying lengths of wire rope. The water was delivered alongside the piers through a 5-inch main, supported on timber piles about 25 feet from and parallel with the line of the bridge, and was conveyed to the foot of the disks, through 3-inch hose and 3-inch wrought-iron pipes let down through the centre of the piles. The hole in the pile foot was 6 inches in diameter. The platforms from which the piles were slung into position, guided and driven, were bolted to movable trestles of the form shown in *Figs. 3 and 4*. These trestles were built of Oregon pine, and, after a pier was completed, were let

Fig. 3.**TRESTLES FOR PILE-DRIVING.**Scale $\frac{1}{4}$ inch = 1 foot.*Fig. 4.***TRESTLE FOR PILE-DRIVING.**Scale $\frac{1}{4}$ inch = 1 foot.

down and floated away to the next position. The two halves were hinged at the top by means of a 3-inch pipe slipped through staples. This system worked very well, and resulted in a considerable saving of time and expense, over what would have been entailed by the use of a fixed scaffolding for each pier. The foot of the frames soon settled into the sand, and bore up very well against the pull of the driving rope. Nine trestles of this description sufficed for the whole of the work.

The piles being slung into position, the first step was to turn on the water jet, and let them down, without turning, through the superficial layer of quicksand. In a short time their own weight thus carried them down 2 or 3 feet. This served to anchor the whole system to a great extent and resist any displacement from the pull of the rope. Next the capstan was fixed to one of the centre piles, the rope wound round, and the winch set going. The average time of rotation for sinking a pile to the average depth attained was about 18 hours. Particulars of the speed and penetration will be found in the Appendix.

The pile-sinking began on the 28th of June, 1888, and ended on the 3rd of October, 1889, occupying, therefore, four hundred and sixty-two days. But, out of this time one hundred and eleven days were occupied in sinking the first and second pier. The actual time employed in sinking these two piers only amounted to forty-four working days, so that sixty-seven days were lost at the outset. This delay was due principally to the exceptional severity of the rainy season of 1888, and also in some measure, to the imperfection of the early methods employed. After the first two piers were driven (on the 17th of October, 1888), the work continued regularly until the end with but slight interruptions. From that date onward, work was carried on by day and by night, with the help of the Wells light, burning paraffin oil. Until the 12th of February, 1889, pile-sinking was carried on upon only one pier at a time. After that date two piers were kept going, and from the 1st of March, three piers were worked simultaneously. Between the 17th of October, 1888, and the 12th of February, 1889, thirteen piers were sunk singly, in one hundred and eighteen days, averaging 9·07 days per pier. Between the 12th of February and the 3rd of October, 1889, two hundred and thirty-three days, the remaining forty-six piers were driven, averaging 5·06 days per pier. Of these two hundred and thirty-three days, fifty-three were lost through holidays or stormy weather, so that the average number of working days occupied in driving each pier was really 3·91, of which 2·09 were taken up in shifting scaffoldings and

machinery, laying out piles, setting platforms and blowing down, and 1·82 in actual pile-driving. The rate of progress would have been much quicker, had the bed of the river been exclusively composed of black sand. The clay bands and occasional patches of gravel traversed, absorbed more than half the time employed in driving. A clay stratum was struck in most piers close to the finishing depth, and the last few inches often took two or three hours to drive. A good many piles stopped short of the full depth, and resisted every effort to move them. For these columns a shorter intermediate length was cast. A few of the 15-inch piles were stopped 10 feet short of the full depth, in extremely tough ground. While the piles were going through pure black sand, their rate of progress was very rapid, often as much as 7 or 8 feet per hour. Very often, when the disk had reached a depth of over 12 feet, the water, being unable to get away under the disk, would return up the interior of the pile, and run over the top, charged with 25 to 30 per cent. of black sand, thus making an excavation under the foot of the pile which materially assisted the descent. The piles ran in guides on the platforms above and below the capstan, and no very great trouble was experienced in keeping them straight; in fact, much less than is generally met with in driving screw-piles.

The number of accidents was very small. A troublesome one occurred in the first pier from the southern bank; the bolts of the second joint from the bottom of one of the 12-inch columns sheared off when very near the full depth, leaving the top part loose. The disk-foot and bottom length were thus left buried beneath 10 feet of sand and 8 feet of water. The extraction of these pieces caused an immense amount of trouble. The flange of the top length was grasped by four steel rails provided with strong steel projecting pieces, water jets were applied to the upper surface of the disk-foot, and the rails were hauled up by four 20-ton jacks bearing on the other piles of the pier, and on an extra one sunk for the purpose. The upward progress of the pile was extremely slow, but after many slips it was eventually extracted and replaced by a sound column. The lifting force exerted was probably about 50 tons.

SUPERSTRUCTURE.

The girders were shipped from England in a comparatively small number of pieces, and were riveted together on the southern bank of the river, whence they were carried and dropped into

their places by a travelling steam crane. The first main girder was placed in position on the 2nd of February, and the last on the 19th of November, 1889. The time actually required between the placing of each span, for riveting the bracing, fixing the timber superstructure and laying the rails was about $2\frac{1}{2}$ days, but these operations constantly overtook the pile-sinking, and were frequently stopped in consequence. In performing this work, which consisted of three trips per span, one with a pair of the small over-pier girders, and one with each of the next main girders, the steam-crane travelled altogether 224 miles.

The bridge was tested under the directions of the Chilean Government Engineer, Mr. Dutillieux. Six spans were selected by him for trial under (a) quiescent load, and two others for trial under (b) running goods trains, and (c) running passenger train respectively.

The train for the A and B trials was composed of a 35-ton engine on a 15-foot 4-inch wheel-base, and ten loaded four-wheel wagons weighing about $18\frac{3}{4}$ tons each on 8-foot wheel-bases. This was the greatest weight that could be applied with the company's rolling stock, the car-springs were nearly down. The average load from the front part of this train was 1.13 ton per foot run, or $92\frac{1}{2}$ tons on the span. The goods train was run at a speed of 20 miles per hour. The passenger train was represented in the trial by a 42-ton engine on a 27-foot wheel-base, and nine loaded four-wheel wagons, weighing 9 tons each, on 8-foot wheel-bases. It was run at 31 miles per hour. The measured deflections in all these tests were about 18 per cent. below the theoretical deflections calculated on assumed moduli of elasticity of 20 tons per square millimetre in tension, and 16 tons in compression (equivalent to 12,900 and 10,300 tons per square inch respectively), for girders supported at both ends. This discrepancy might to a small extent be accounted for by the bolting down of one end of the main girders, which, however, does not constitute a fixed end in the fullest sense of the term, and by the rigidity of the timber longitudinals. But by far the greater part of the margin is no doubt due to the good quality of the iron. No permanent set was observed. It had probably all been taken out by the travelling-crane.

The communication is accompanied by a series of drawings from which the cuts in the text have been engraved.

APPENDIX.

I.—NOTES ON PILE-DRIVING.

THERE were sixty piers composed of six piles each, and one pier composed of nine piles. (This arrangement was necessary in order to establish the abutments at a safe distance from the edge of the river bank.) These sixty-one piers contained one hundred and twenty-three piles, of 15 inches outer diameter, and two hundred and forty-six piles of 12 inches outer diameter. The one hundred and twenty-three 15-inch piles penetrated in the aggregate 2,986 feet into the sand. The average penetration of the 15-inch piles was thus 24.28 feet. This penetration was the result of two thousand three hundred and sixty-eight hours' rotation of the columns. The average speed of penetration for the 15-inch piles was thus 1.261 foot per hour.

The two hundred and forty-six 12-inch piles penetrated 6,837 feet. The average depth of sand reached by the 12-inch piles was thus 27.80 feet. This penetration was the result of four thousand two hundred and seventy-nine hours' rotation, the average speed of penetration for the 12-inch piles was therefore 1.598 foot per hour.

In twenty-two piers out of the sixty-one, all piles of both kinds reached the regulation depth, about 55 feet below rail-level, and penetrated into the sand on the average 28 feet 6 inches. In these twenty-two piers, the forty-four 15-inch piles took eight hundred and forty hours' driving, and the eighty-eight 12-inch piles one thousand two hundred and seventy. The average penetration-speed in these twenty-two piers, which may be taken as a standard of the work on account of the uniform nature of the soil traversed, and the uniform depth attained, was 1.493 foot per hour for the 15-inch piles, and 1.975 foot per hour for the 12-inch piles. The penetration-speed of the 15-inch piles was thus 0.756 of the speed of the 12-inch piles. The area of the disk-foot of the 12-inch piles is about 0.735 of the area of the 15-inch pile-feet, so that the speed of penetration appears to have been approximately in inverse ratio to the area of the disk-foot. The amount of water supplied per hour was the same in both cases, but the 15-inch piles required greater power and a slower rate of rotation than the 12-inch piles. The winches had to run more frequently in double purchase when driving the larger piles. In these twenty-two piers, the average time of driving each 15-inch pile was 19.09 hours, and for each 12-inch pile 14.43 hours.

SUPPLY OF WATER AND MOTIVE POWER.

The usual amount of water supplied to each pile was 5,000 gallons per hour at 45 lbs. pressure in the main. This quantity was amply sufficient for the 12-inch piles, and no appreciable advantage was observed to arise from an increased supply in driving them. With the 15-inch piles, however, the speed of penetration was somewhat accelerated by an increased delivery, but not to an indefinite extent, and for this class of pile the maximum useful effect was attained from a supply considerably smaller than the maximum available quantity, which was 10,000 gallons per hour when only one pier was at work. The actual work performed under the disk-foot, whatever might be its nature,

appeared to depend greatly upon the head of water inside the pile. In the 12-inch piles the water generally filled the pile nearly to the top and very frequently overflowed. In the 15-inch piles this result was more rarely attained. The extra quantity of water required to place the larger pile in similar conditions to the smaller one in this respect, would depend mainly upon the relative contents of the cylinders, and, to a smaller extent, upon the relative surface of ground opened up by the disks. Neglecting the latter element, the contents of the 15-inch piles were about 40 per cent. greater than the 12-inch piles. In practice about that amount of increase seemed to satisfy the requirements of the case.

The water was delivered from the main at 45 lbs. pressure per square inch. The maximum pressure from head of water inside the pile, when full depth was being reached, would amount to 18 lbs. per square inch. The motive power for the rotation of the piles consisted of double cylinder steam-winchs with cylinders, 7 inches diameter by 12 inches stroke, supplied from boilers of from 16 to 18 HP. working up to 90 lbs. pressure. The highest speed of rotation of the piles was about 13 revolutions per minute, but they usually revolved at 10 turns per minute with the winch in single purchase. The capstans were from 7 to 8 feet in diameter, and polygonal in figure.

The conditions which govern the work performed by the water-jet are so complex, and probably vary so much in respect of the quality of the sand and other strata traversed, that it would be rash to lay down empirical formulas based upon this single case. This consideration is equally applicable to the amount of motive power required for the rotation of the piles. However, the Author believes that the capabilities of the hydraulic-jet system have been tested to the utmost in the Bio-Bio bridge, and that considering the nature of the stuff traversed, the largest size of disk has been used which could conveniently have been driven down by this means. The rotating-power has proved amply sufficient for all purposes, the water-supply but slightly deficient for a portion of the work. The Author therefore considers that the quantities, both of motive power and of water used at the Bio-Bio bridge, may be fairly regarded as maxima for almost any case in which the adoption of the water-jet system may be technically or economically advisable.

II.—DETAILS OF COST OF THE BIO-BIO BRIDGE.

	£	s.	d.
The total cost of the bridge was . . .	74,500	0	0
The iron piers cost	40,578	0	0
The superstruction	33,498	0	0
The two brick abutments	424	0	0
The total cost of the bridge per span was	1,201	12	3
The average total cost per foot run of bridge was }	12	3	5½
The average cost of each iron pier com- plete was }	659	16	0
The materials of each pier	251	15	0
Ditto delivered in San Pedro, and erected	408	1	0
The average cost of sinking the six piles of each pier was }	377	10	2

	£	s.	d.
Considering the length of time respectively employed in sinking either class of pile, the proportionate average cost of sinking a 15-inch pile was	67	5	0
Sinking a 12-inch pile	60	15	0
The total cost of the wrought-iron girders, ready erected, was	29,486	0	0
The timber superstructure	2,921	0	0
The handrailing	1,091	0	0
The average cost of each complete span of superstructure was	540	5	10
The average cost of the complete superstructure per foot run of bridge	5	9	5
The cost of the wrought-iron girders per foot run of bridge amounted to	4	16	4
(Of which £3 14s. 9d. represents the value of the iron work delivered in San Pedro, and £1 1s. 7d. the cost of erection.)			
The timber superstructure cost per lineal foot	0	9	6
The handrailing per lineal foot	0	3	7

The cast-iron piles, together with wrought-iron packing-plates and nuts for same, cost £10 3s. 11d. per ton delivered in San Pedro.

The wrought-iron girders cost £12 11s. 2d. per ton delivered in San Pedro. They cost £9 15s. in England.

The following general statement of cost may, perhaps, present some interest :—

No. 1.			
		£	£
Materials	Value of materials of bridge	31,108	
	Freight and purchasing-charges on same	9,890	
	Brick abutments	424	
			41,422
Erection	Tools, stores, appliances, plant, and buildings	14,513	
	Freight and charges on same	609	
	Labour in erection	16,004	
	General expenses	1,952	
			33,078
Total			74,500
		£	s.
Cost of materials per lineal foot of bridge		6	15 4½
,, erection per lineal foot of bridge		5	8 1
		£12	3 5½

	No. 2.	£	£
(A.) <i>Piles and Pile-sinking—</i>			
Value of cast-iron piles	12,590		
Plant, tools, and stores for pile-sinking	10,825		
Coal	1,551		
Labour in pile-sinking	9,975		
Proportion of general expenses	1,366		
			35,807
(B.) <i>Erection of upper columns and pier-bracing—</i>			
Value of wrought-iron pier-bracing	2,893		
Plant, tools, and stores for erection	437		
Labour in erection	1,245		
Proportion of general expenses	196		
			4,771
(C.) <i>Girders—</i>			
Value of girders	22,872		
Plant, tools, and stores for erection	2,421		
Coal	388		
Labour in erection	3,415		
Proportion of general expenses	390		
			29,486
(D.) <i>Timber superstructure—</i>			
Value of timber superstructure	1,660		
Labour in erection	1,261		
			2,921
(E.) <i>Handrailing—</i>			
Value of handrailing	983		
Labour in erection	108		
			1,091
(F.) Brick abutments			424
			<u>£74,500</u>

No. 3.

DETAILED COST OF PLANT, TOOLS, AND STORES FOR PILE-SINKING.

1. Launches, boats, &c.	£417
2. Pumps, pumping-plant, pipes, &c.	2,834
3. Scaffolding	1,412
4. Lifting-tackle	863
5. Steam-winches and turning-tackle	1,273
6. Wells light	252
7. Oilskin suits and tarpaulings	211
8. Proportion of cost of buildings and of general tools, stores, and appliances	3,063
	<u>£10,325</u>

(Paper No. 2615.)

"The Rosario Water-Works, Argentine Republic."

By ALEXANDER FAIRLIE BRUCE, Assoc. M. Inst. C.E.

(*Abstract.*)

ROSARIO DE SANTA FÉ, the second city of the Argentine Republic, forms an irregular triangle having the River Paraná for its base, and, like most American towns, is laid out in rectangular blocks. Except along the Barranca, or river bluff, which is from 50 to 60 feet high, it is almost absolutely flat. There are about five thousand houses, of which not more than six hundred exceed one storey in height, and about two thousand other erections of a more or less temporary character. Until recently the population of the city numbered about 70,000. It is an important railway centre, and the principal port for the northern provinces of the Republic. Until the waterworks were established, Rosario was dependent for its supply (a) on wells sunk from 50 to 60 feet to a sandy stratum in communication with the river; (b) on "algibes," or rain-water tanks, holding from 4,000 to 5,000 gallons, sunk below the patios, or courtyards of the houses; (c) on water-carts, which, in dry seasons, delivered muddy water at high prices. The cesspool system prevails, the receptacles consisting of wells identical in character with those which formerly furnished the water-supply. All water used for washing purposes is allowed to run through badly constructed brick drains into the street gutters. Under these conditions the death rate gradually rose to between 60 and 70 per thousand, and at times to 80 per thousand.

In March 1886 the River Plate Trust, Loan and Agency Company acquired the rights of a concession granted to supply the city with water from the Paraná, and works were commenced, from the designs of Mr. Edward Easton, M. Inst. C.E., comprising a pumping-station on the Paraná, about 3 miles above the city, settling reservoirs, two filter beds, a water-tower and piping for about half the present town. The engines were compound, of the condensing beam type, developing 100 indicated HP. with steam at 85 lbs. pressure. There were two sets of pumps, one being of

the direct-acting bucket-and-plunger type, capable of delivering 1,314 gallons per minute, and the other on the so-called continuous-acting system, with two barrels placed side by side in a well, and designed to deliver 1,230 gallons per minute. The settling reservoirs were constructed with earthen banks, 9 feet high, 5 feet thick at the top, with internal slopes of $1\frac{1}{2}$ to 1, lined with concrete. The two filters, 130 feet by 170 feet, had an area of 20,750 square feet, the filtering medium consisting of 20 inches of sand, and from 4 to 6 inches of gravel. The main, $2\frac{1}{2}$ miles long, to town, was 20 inches in diameter, and capable of delivering 3,000,000 gallons in twenty-four hours, with a frictional head of 16 feet. At the end of the main was a water-tower, with a tank containing 45,000 gallons, which allowed the engines to be stopped for short intervals.

In 1888 the Author was appointed engineer to the company, and found that the settling reservoirs were in a dangerous condition, owing to the banking having subsided from the concrete, which had cracked in all directions, and allowed water to pass through freely. The filters, being in direct communication with the pumps, and having no receptacle for the accumulation of filtered water, could only work intermittently, under a head varying from 6 feet downwards, according to the rate of pumping. Having also an insufficient thickness of gravel, they were constantly washed into holes, and the water passed into the pipes in a more or less unfiltered state. It was therefore found necessary to reconstruct the sides of each of the three reservoirs next to the filters, and extensively repair the remainder; also to re-establish the filter-beds, giving to No. 1 a thickness of 12 inches of gravel, and to No. 2 24 inches, the thickness of the sand being retained at 20 inches in each case.

In 1889 it was decided by the Board to extend the works by the construction of a clear-water reservoir, an additional settling-reservoir, and a filter-bed, and to increase the pumping power in order to keep pace with the growing consumption. These new works were completed from the Author's designs, and form the principal subject of the Paper. The clear-water reservoir was of circular form, 131 feet 3 inches in diameter (40 metres), and 13 feet deep, including the pump-well. Its capacity was about 1,050,000 gallons, or eight hours' filtration of the two filters working together. The sides were lined with concrete, 12 inches thick at the top, battering to 2 feet 5 inches at the bottom, backed with 6 inches of puddle. The floor was of concrete, 6 inches thick. The covering consisted of jack-arches of 6-inch brickwork in 3-foot spans, carried on old 60-lb. rails, 20 feet long,

and fished together. These were supported by rolled beams, 12 inches by 5 inches, spaced 10 feet 6 inches apart, with 15 feet spans. These were carried by cast-iron columns 10 inches in diameter. Including the 2-foot covering of earth, the weight carried by each column was about 18 tons.

The new filter-bed had the same external dimensions as the old one, but the filtering surface was increased to 22,100 feet. The walls were of concrete, 18 inches thick at the top, battering 1 in 10 to 2 feet 4 inches at the bottom. Settling reservoir No. 4 was placed in line with the others. It measured 213 feet by 197 feet 6 inches, and was 8 feet 6 inches deep, containing about 2,250,000 gallons; its construction was similar to that of the new filter-bed.

Nearly all the bricks used in the works were made on the spot. A circle, about 40 yards in diameter and 12 inches deep, was cut in the ground. Into this was thrown the quantity of earth (upper surface of the alluvial soil) necessary to make a kiln of bricks. This was mixed with straw and dung, then watered and trampled to the desired consistency by mares. The bricks were moulded, sun-dried, and then placed in clamps containing from 40,000 to 120,000, mixed with layers of coal-dust and cinders, the fire being kindled below with wood and brushwood, maize-straw, &c. The bricks thus made measured $11\frac{1}{2}$ inches by $5\frac{1}{2}$ inches by $2\frac{1}{4}$ inches, and, if well made, were very durable, though somewhat porous, absorbing about 10 per cent. of their own weight of water. The sand and gravel were obtained from the Paraná. Portland cement was used throughout, specified to contain not more than from 60 to 62½ per cent. of lime, to leave a residue of not more than 10 per cent. on a sieve of 2,500 meshes to the square inch, and to have a tensile strength of 350 lbs. per square inch on the seven-day test. The concrete was made of 5 parts of broken brick, 3 parts of sand, and 1 part of cement.

The new engine was of the Worthington triple-expansion vertical type, made by Messrs. Simpson, of London. The cylinders were respectively of $10\frac{1}{2}$, $16\frac{1}{2}$, and 26 inches diameter in pairs, the admission valves of one set being worked by the piston-rod of the other. One set gradually came to rest as the other attained full velocity, thus obtaining a constant uniform action, contrasting very favourably with that of the beam-engines, which gave a shock of from 4 to 10 lbs. to the pipes at every stroke.

With two filters in operation, two engines working simultaneously could deliver from 3,000,000 to 4,000,000 gallons in twenty-four hours; but, owing to the limited size of the pressure-tank in town, and to the fact that from 80 to 90 per cent. more water was

used during the hours of maximum draught than at other times, not more than 2,250,000 gallons were pumped on the average. Owing to the intermittent nature of the pumping, and to the deterioration of the coal from exposure to a hot sun, the consumption was heavy as compared with work done. When the works came under the Author's charge, it amounted to 8 lbs. per 1,000 gallons pumped. It had since been reduced to 5 lbs. per 1,000 gallons, and the cost of pumping 1,000 gallons from $8\frac{1}{2}$ cents (gold) to $4\frac{1}{2}$ cents, equal to 2·7 cents if pumped 100 feet high. The whole cost of water as delivered to town was 3d. per thousand gallons, which, with coal at 45s. per ton, was not exorbitant. It was proposed in future to use Quebracho wood for fuel, which has a heating value of about two-fifths that of coal, and it was anticipated that an economy of 40 per cent. would be thus obtained, although the labour of stoking would be somewhat increased.

The cost of the extension works, which were carried out by the Author without the intervention of a contractor, was as follows:—

	£	s.
Clear water reservoir	3,935	10
Settling reservoir	2,289	0
Filter-bed	2,437	0
New engines and engine-house	4,019	0
Pipe-laying in town	15,000	0
House for staff at pumping-station	500	0
Repairs to old filters	1,000	0
Total	29,180	10

The original Paper is accompanied by a series of drawings, and gives in an Appendix full details of the cost of the various works carried out, and of the prices of labour and materials; also trials of the Worthington pumping-engine, with indicator diagrams relating thereto.

(Paper No. 2556.)

“The Manufacture of Transverse Steel Sleepers of the Inseparable Clip Type for Permanent Way.”

By HERBERT KELWAY BAMBER.

THE use of transverse steel sleepers for permanent way on Indian and Colonial railways, as substitutes for wooden sleepers, has given rise to an important and increasing industry. Numerous types have from time to time been designed, and experience has shown that sleepers, to be both effective and economical, must be simple in design, with as few fittings as possible, and present no great difficulties in manufacture.

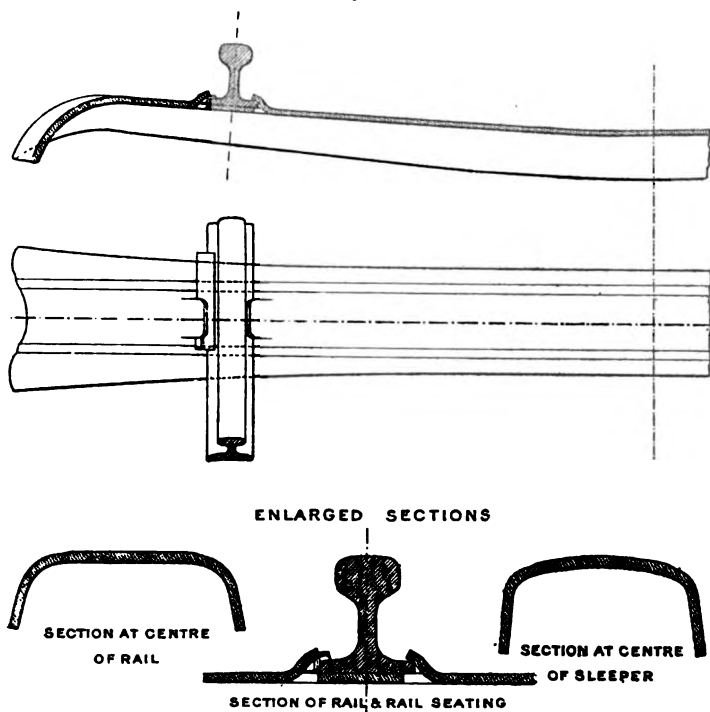
During the execution, under his supervision, of large orders for steel sleepers, the Author has frequently had occasion to trace the causes of failures which have from time to time occurred, and in this way has obtained information which he hopes may be of use to engineers and sleeper-makers alike. It is his intention in this Paper to deal only with such of the “inseparable clip” type of steel sleepers as have passed beyond the experimental stage, have so far satisfactorily stood the test of time and are still in use on main lines in this country or on Indian and Colonial railways.

The sleepers of this type, which have so far in the Author's opinion given the most satisfactory results, are those designed by Sir A. M. Rendel, M. Inst. C.E., and Messrs. Cabry and Kinch. Both of these are suitable for use with flat-footed or flange rails, the rail-fastenings being formed by punching up a part of the material of the plate itself to form clips or jaws, in which the rail is held by steel taper keys. These clips or jaws are punched at such a distance apart that when the rail flanges bear against them, the desired gauge or distance between the rail heads is obtained, while the only separate part required is the taper steel key, which, being driven between the rail flange and the opposite jaw to that determining the gauge, forms a rail-fastening both simple and secure.

Figs. 1 represent the standard sleeper of this type, as used on the Indian State, Mexican, and other railways of different gauges. The section at the rail-seat, as shown on this drawing, illustrates the method of rail-fastening as adopted on these sleepers.

Each rail has a bearing surface on the sleeper of 18 square inches, and is held in position by the two jaws, which, as before stated, are formed by punching up portions of the sleeper plate itself; the taper key being driven between the outer or inner jaw and the rail flange. These sleepers are made from rolled steel plates, the section of which is fish-bellied, or padded, that is, with a thickened part rolled down the centre; in both cases the

Figs. 1.



thickness is usually about $\frac{3}{8}$ inch along the centre, and about $\frac{1}{4}$ inch at the edges.

The rolled plate is pressed to shape under suitably shaped dies, the jaws being punched. They are dipped at a temperature of about 300° Fahrenheit in a boiling solution consisting of 3 parts coal tar and 1 part tar oil, which forms a good hard coating. It will be seen that the space between the edges of the jaws is less than the width of the rail flange; it is therefore necessary to tilt

the rail to put it into place. This has the disadvantage of preventing the removal of one sleeper independently of the rest in a length of rail, as, in order to remove one, the two rails must be uncoupled and taken off; on the other hand, the rail cannot leave a sleeper should the keys become displaced.

The details of Indian State sleepers of the standard type are :—

Gauge.	Length of Plate.	Width of Plate.	Weight.	Weight of Two Keys.	Weight per Mile.
metre. Feet Inches.	Feet Inches.	Inches.	Lbs.	Lbs.	Tons Cwt.
5 6	5 9	12	69	1·25	55 4
	8 9	13½	120	2·00	95 17

The manufacture of these sleepers forms a very large industry, and is carried on at a number of the most important steel works in this country, one firm alone having manufactured up to the present time a total quantity of 130,000 tons, or two millions eight hundred thousand sleepers. The tools used in their manufacture have been greatly improved from time to time, and the firm above mentioned can turn out finished sleepers of the metre gauge at the rate of ten per minute.

The advantages claimed for these sleepers are as follows :—

1. They are easily handled and laid in the track.
2. They hold well in line and surface.
3. The gauge can readily be adjusted on curves, by keying up one or both of the rails inside.
4. The clips are not too rigid, and the keys keep well in place when once properly driven up.
5. The maintenance is easy when the track has once become consolidated.
6. If damaged by derailment, the sleeper can be repaired and made serviceable at small cost.
7. Except where ballast has been impregnated with saltpetre, &c., the sleepers have not been found to rust much.

NORTH EASTERN RAILWAY.

Messrs. Cabry and Kinch's Sleeper.—Sleepers similar to that shown by *Figs. 2*, as designed by Messrs. Cabry and Kinch, of Darlington, were put down experimentally on the North Eastern Railway in 1887.

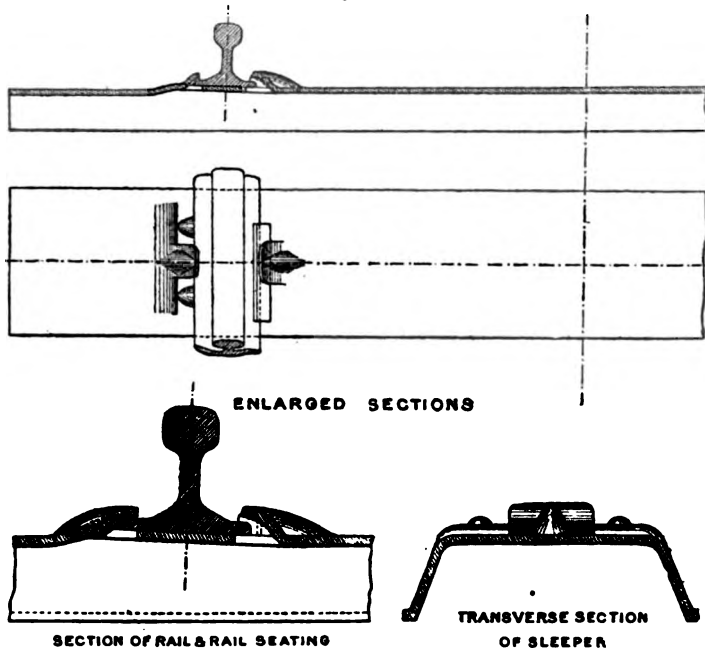
It will be seen that this sleeper is of inverted trough-section with open ends, having a narrow flange or rib rolled along its lower edges, which stiffens the plate, but it is not wide enough to

interfere with the proper bedding of the sleeper in the ballast, as was the case with the old sleepers of the Vautherin type.

The rail-fastenings or clips of this sleeper are formed by hydraulic pressure entirely out of its own substance, as in the case of the Indian State sleeper. Both the inner and outer clips of this sleeper have their backs buckled or corrugated, which considerably increases their stiffness.

This sleeper is also furnished with two studs, or what may be called "rudimentary clips," punched up, one on each side of the

Figs. 2.



outer clip, in the same manner and at the same time with the clips proper. These two studs, being slightly nearer the rail flange than the root of the outer clip, relieve the clip of nearly all thrust, its office then being chiefly to keep the rail down. The outer clip is $2\frac{1}{2}$ inches wide and covers the rail flange for $\frac{5}{8}$ inch; the inner clip is $3\frac{1}{2}$ inches wide and covers the rail flange for $\frac{3}{8}$ inch, the steel taper key being driven between this clip and the rail flange. The keys are 8 inches long and have a taper of about 1 in 64. These sleepers, however, can only be keyed on the inside, and

therefore the gauge cannot be widened except by the use of special sleepers. The tilt of the rail is obtained by pressing up to the requisite angle that portion of the sleeper only which is immediately under the base of the rail. This enables the sleeper to be laid horizontally and prevents transverse motion in the ballast. The ends are thus able to be left open.

The rail is placed in position by tilting it and passing one side of the flange under the inner or longer clip, sufficient space being left for the outside of the flange to clear the shorter clip. It is then dropped on to the rail-seat and slid back under the shorter clip, and the steel taper key is inserted between the rail flange and the longer clip, and driven firm. It will be seen that the flange is overlapped by both clips, and that the rail cannot be forced out of position, even should the keys be displaced.

The details of this sleeper are :—

Gauge.		Length of Plate.	Width of Plate.	Weight.	Weight of Two Keys.	Weight per Mile.
Feet	Inches.	Feet.	Inches.	Lbs.	Lbs. Ozs.	Tons. Cwt.
4	8½	8	16	150	31 2½	132 5

The sleepers are spaced eleven to a rail length of 30 feet, and the distance from each end of the rail to the centre of the first sleeper at that end is 11 inches. The remaining nine sleepers are spaced at equal intervals of 2 feet 9½ inches apart. A notable feature in this form of permanent way is the steel flange rail, which weighs 91 lbs. per yard and has a flange 5½ inches wide. The rail-bearing surface of the sleeper, in the direction parallel with the rails, is 8 inches wide, and the total bearing of the rails upon the sleeper at each end is 44 square inches. It has been found that the steel taper keys, when once driven tight, do not slack back, and their small ends are therefore no longer split, which greatly lessens the cost of their manufacture. In India, however, where the steel of which the keys are made is much prized and sought after by the natives for the manufacture of small tools, it is still found necessary to split and open the ends. As regards the length of life of these sleepers, nothing can yet be said with certainty, as they have only been in use since 1887, but the Author is informed that there has as yet been no failure of the clips.

Mr. Riley's Sleepers.—Another form of sleeper of the “inseparable clip” type, but one which has perhaps not yet been brought prominently before the engineering world, is that introduced by

Mr. Riley, of the Steel Company of Scotland, in 1885, and used to some extent on the North Eastern Railway. The peculiarities of structure of these sleepers are shown by *Figs. 3 and 4*. They are made by rolling the section thicker at the part destined to receive the rail, and by thrusting the ends of the plate together, so as to collect sufficient material to form the jaws. Both the inner and outer clips are first pressed into the form of the outer, and the inner is then forced into the shape shown by the use of special dies. Provided the metal of which these sleepers are made is of a sufficiently mild quality, and worked only at a proper heat, they might be successfully used; but it appears to the Author that, unless these conditions were rigidly adhered to, the amount of strain set up by cold working would be such as to cause the number of defective plates to be very great.

Having now noticed the three principal types of sleepers with inseparable clips, the Author proposes to describe the method of their manufacture.

THE QUALITY OF STEEL TO BE USED.

The quality of the steel to be used in the manufacture of sleepers, whose rail fastenings are formed out of, and are in a piece with, the sleeper itself, is of the utmost importance, and steel makers have had to study this matter very carefully.

The specified requirements of sleeper steel at present are:—

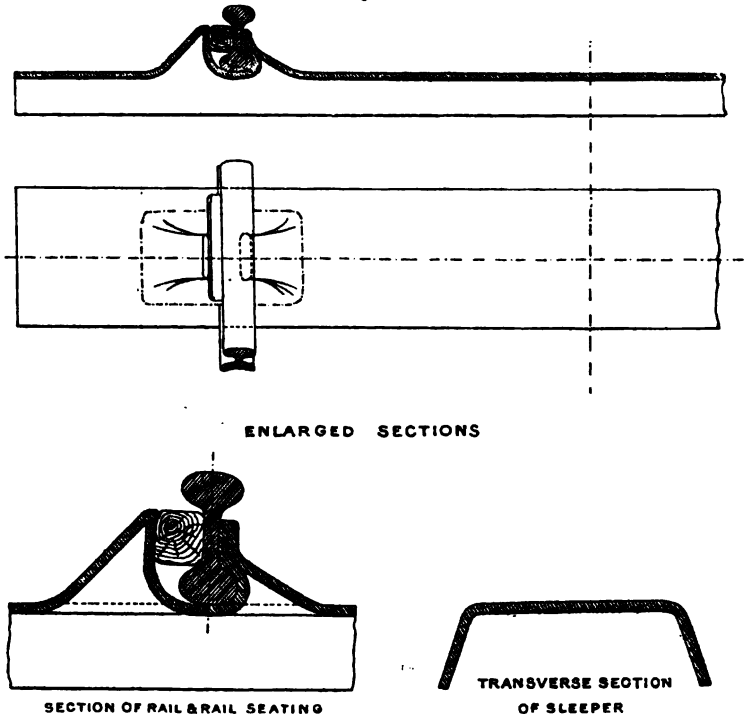
1. That it shall be as even as possible in quality.
2. That it shall withstand an ultimate tensile stress of at most from 26 to 31 tons per square inch.
3. That it shall elongate at least 20 per cent. in a length of 10 inches.
4. That it shall show a contraction of area at point of fracture of not less than 40 per cent.
5. That it shall be capable of being bent double on itself to an inside radius of one half its mean thickness, without sign of crack or fracture.

The steel used is made by the Bessemer, Thomas, and Siemens-Martin processes, this material possessing the qualities of homogeneity, malleability, and ductility. The first of these qualities depends largely on the proper mixing of the steel, effected either by means of a mechanical stirrer, which is lowered into the ladle containing the metal which has just been run from the converter, and made to revolve at about 100 revolutions per minute, or by blowing the metal at such a temperature as to permit of its being poured from the converter into an intermediate ladle, thence into the casting-pit ladle, and finally into the ingot moulds, in a suffi-

ciently fluid condition, which can only be done when pig-iron sufficiently high in silicon is used.

The object of this mixing is to ensure sufficient and uniform distribution throughout the iron, of the manganese which has been run into blown metal to permit the escape of occluded gases, and to ensure the tranquillity of the metal after being poured into the ingot moulds.

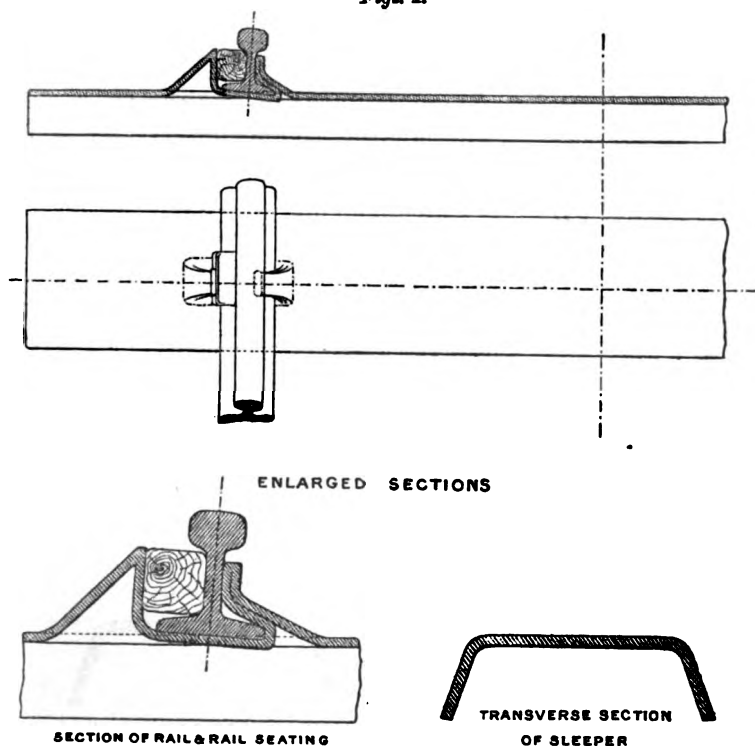
Figs. 3.



There seems to be no doubt that want of sufficient mixing is the reason why sometimes, in a dozen sleepers cut from one length of rolled plate, all having been punched with equal care, some of the clips fail under the bending test, before reaching an angle of 90° , while others can be bent double and hammered down on the back of the sleeper without fracture. It has been the Author's experience that this want of regularity of quality is greatest when the metal, after the addition of the manganese, is perhaps blown again for a few seconds, and not afterwards mechanically mixed by either of the two methods above mentioned.

The analyses of the class of steel used by the five chief sleeper makers in the kingdom, and the results of tensile tests showing the quality and range of each, are given below. The analysis in each case corresponds with the "medium" quality of the steel given under each number, and the tensile tests, which

Fig. 4.



ANALYSIS OF "MEDIUM" STEEL.

Number	1	2	3	4	5
Process of manufacture	Acid	Acid	Acid	Basic	Basic
Carbon	0.13	0.12	0.12	0.09	0.11
Silicon	0.03	0.01	0.02	nil	0.02
Sulphur	0.06	0.06	0.05	0.05	0.05
Phosphorus	0.06	0.06	0.05	0.06	0.05
Manganese	0.40	0.40	0.70	0.42	0.75

RESULTS OF THE TENSILE TESTS OF THESE STEELS.

Quality	"Medium"				
Load per square inch, Tons	30·41	27·38	27·31	28·30	29·90
Elongation per cent. in 10 inches	23·00	26·50	21·56	24·50	23·00
Contraction per cent. . . .	46·00	56·00	not taken	not taken	48·00

were made during the execution of orders, represent hundreds of thousands of tons of steel. It will be understood that the terms "soft," "medium," "hard," are used relatively, for the purpose of showing the range and averages of the different steels.

The range of each of these steels, as shown by the result of numerous tensile tests, is given below :—

Number	1	2	3	4	5
Quality	"Hard"				
Load per square inch, Tons	32·50	28·73	29·63	29·30	33·70
Elongation per cent. in 10 inches	22·65	25·00	22·30	23·00	22·50
Contraction per cent. . . .	39·08	59·50	not taken	not taken	46·00

In order to show that steel of a higher tensile strength than 31 tons is not suitable for use in the manufacture of these sleepers, the Author proposes to give the analyses and the results of tensile tests of steel, taken from the backs or thickest parts of some sleepers which had broken in two by falling on a hard substance when being discharged from railways wagons. They were all made under one order.

ANALYSIS OF STEEL.

—	a	b	c	d	e
Carbon	0·15	0·15	0·15	0·14	0·15
Silicon	0·05	0·04	0·05	0·05	0·05
Sulphur	0·06	0·06	0·058	0·055	0·06
Phosphorus	0·08	0·08	0·083	0·08	0·08
Manganese	0·46	0·47	0·45	0·47	0·49

TENSILE TEST-PIECES (unannealed).

—	a	b	c	d	e
Load per square inch .	39·60	36·00	37·00	36·66	34·00
Elongation per cent. in } 8 inches }	nil	13·67	14·22	14·45	2·74
Contraction per cent. .	nil	42·00	38·00	40·00	practically nil

TENSILE TESTS (annealed).

—	a	b	c	d	e
Load per square inch . . .	32·50	32·50	32·50	33·33	32·50
Elongation per cent. in 8 } inches }	21·09	23·83	30·31	23·44	23·84
Contraction per cent. . . .	48·00	48·00	52·00	42·00	46·00

Taking the analyses and results of annealed tensile tests of sleepers *a*, *b*, *c*, and *e*, and allowing for some little inequality in the mixing of the steel at the time of blowing, it would appear as though these four sleepers had been made from one rolled bar, so closely do they compare with each other. The effect of annealing, as shown in these results, is very interesting.

It was evident that these five sleepers had been made from plates which had been "cold rolled," that is, they were not at a proper heat at the time of rolling, either from neglect at the furnace, or through some delay after reaching the roughing rolls. The subsequent punching up of the clips at too low a heat had developed strains, starting at an angle of 45° with the root of the clip, along which lines of strain each sleeper ultimately broke.

The lesson to be learnt from these experiments seems to be, that steel having a tensional strength of 32·5 tons per square inch is not suitable for use in the manufacture of sleepers which have to withstand strains caused by the punching up of portions of the plate, because by working the steel at too low a heat, strains may be set up by the subsequent operation of punching, to such an extent as to cause fracture, as in the cases just considered. It is the Author's experience that, if in the ordinary course of manufacture, the steel be kept at about 28 tons tensile strength per square inch, the clips may be bent double without any fear of fracture taking

place; but when of such tensile strength as to withstand 31 tons per square inch, at least 4 per cent. of the clips will fail on being bent to an angle of 90°. He is, therefore, of opinion that steel used in the manufacture of sleepers of this type, should be allowed to range between 26 and 30 tons, and he finds that the steel which gives in all respects the most satisfactory results, is that which answers to the following analysis and tests:—

STANDARD SLEEPER STEEL.

—	Analysis.	—	Tensional Strength.
	Per cent.		Tons.
Carbon	0·12	Load per square inch	28·00
Silicon	0·02	Elongation per cent. in 10 inches	24·00
Sulphur	0·05	Contraction per cent.	50·00
Phosphorus	0·05		
Manganese	0·70		

The steel should be capable of being bent double on itself to an inside radius of one half its mean thickness, without sign of lamination, crack, or fracture.

In designing a steel sleeper there are questions to be borne in mind, no less important than that of the absolute perfection of the design.

These questions are:—

1. What processes will the carrying out of this design involve?
2. How far will these processes be more costly than the value of any peculiarities of the design in question warrants? How far can uniformity of results be relied upon, taking into account the liabilities of variation in the action of machinery, &c., and the special training of the men to be employed, either in the course of manufacture or the laying down of the track?

In dealing with the details of sleeper manufacture, such as the rolling and shaping of the plates, the formation of the rail-fastenings, and lastly, the method of preserving the sleeper from rust, the Author proposes to note the principal defects, the causes of which he has from time to time investigated.

The various processes of manufacture from the time of the casting of the steel ingot are:—1. Reheating and cogging of ingot; 2. Shearing of rolled ingot into suitable lengths, and reheating of these lengths; 3. Roughing, finishing, shearing, or sawing of sleeper plates; 4. Shaping of the sleeper; 5. Formation of rail

fastenings; 6. Coating of sleeper; 7. Testing and inspection of finished sleepers.

REHEATING AND COGGING OF INGOT.

When a mill is capable of keeping pace with the manufacture of steel, the ingots, on being brought from the casting pit, can be at once charged either into a furnace or a soaking pit, and raised to the proper rolling heat. By this means a sound ingot is obtained, and a great saving of fuel effected. If this cannot be done the ingots are stocked, and afterwards reheated as required. Cold ingots, on being reheated, frequently crack internally with a loud report, and result sometimes in laminated plates and other defects. The size and weight of ingots varies according to the method of rolling adopted, and the number of plates to be rolled from each ingot.

There are two methods of rolling steel sleeper plates—1. Into the form of flat plates. 2. Into the form of trough-shaped plates.

In the first case, for sleeper plates $13\frac{1}{2}$ inches wide, the section of ingots at about half their length measures 10 inches by 17 inches; while in the second case, the section at the same point is 15 inches square. In either case the weight of the ingot varies from 20 to 30 cwt.

The important point to be remembered, in the rolling of soft steel into thin and narrow plates of great length, is that the metal, unlike hard steel or iron, on being rolled, does not tend to spread in the direction of the width of the plate; and therefore the ingot should always be wide enough to permit of a sufficient amount of compression on the sides which will ultimately form the edges of the plate.

THE COGGING OF INGOTS FOR FLAT PLATES.

A plate, such as used in the manufacture of the sleeper shown by *Figs. 1*, will be rolled in the following manner.

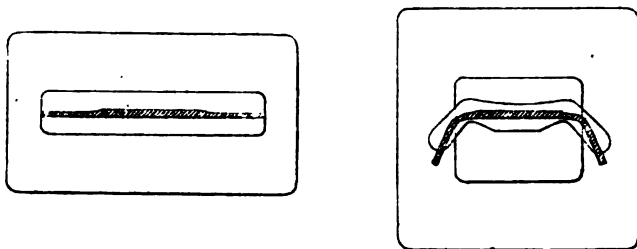
The ingot measures 10 inches by 17 inches, and the first operation consists in cogging this ingot down to a section measuring $2\frac{1}{2}$ inches by 14 inches, *Figs. 5*. It will be seen that compression to the extent of $7\frac{1}{2}$ inches has thus taken place in the direction of the thickness of the plate, and 3 inches in that of its width; the latter being effected by turning the ingot (which now measures $2\frac{1}{2}$ by 17 inches), and passing it through an "edging groove," whose cross section is $2\frac{1}{2}$ by 14 inches. This passage through the "edging groove" is the great feature in securing sound flat plates,

and before ingots were compressed in this manner, it was almost impossible to obtain a length of plate which was perfectly sound on its edges.

THE COGGING OF INGOTS FOR TROUGH-ROLLED PLATES.

The sleeper shown by *Figs. 1* may also be made from plates rolled in trough form, in which case the ingot would measure 15 inches square, and would be coggged down to a section measuring 8 by $6\frac{1}{2}$ inches, as shown by *Figs. 5*, a compression respectively of 7 and $8\frac{1}{2}$ inches. The advantage to the sleeper maker, of rolling plates in trough form, is that the same ingot moulds and cogging rolls may be used as for rails, whereas

Figs. 5.



special moulds and cogging rolls have to be used for flat plates, unless the rolls have been designed for both rail and sleeper ingots.

In connection with ingots the chief points to be watched are :—

1. That the bottom of the mould is perfectly free from sand before the molten metal is run in, otherwise small stones and grit are sure to be disseminated throughout the greater part of the ingot, causing sand cracks and other imperfections in the finished plate.
2. That care is taken that the empty space at the top of the mould is properly filled with sand, and that the cover is clamped down as soon as possible, so that the ebullition of the metal does not draw much sand into the interior of the ingot.

SHEARING AND REHEATING OF INGOT.

When an ingot has been coggged down to the required section, its crop ends are sheared off, and it is divided into suitable lengths called slabs, or if rolled into trough plates, it is merely cropped, the full length being then reheated, or, as it is technically termed, "wash heated." The number of lengths into which an ingot is

divided is an important matter, and should be as small as possible, since for each length there will be two crop ends to be removed on the length of plate as it leaves the finishing rolls. The wash-heating of the slabs should be conducted with great care, as any local variation in their heating is sure to result in bad sections and great range of weight per plate. It is a rule that the end of an ingot or slab, which has been nearest to the door of the furnace and is therefore not so hot at the other end, shall enter the rolls first, so that as far as possible the heat, and therefore the degree of softness of the metal, may be uniform. Beyond the necessity of uniformity in heating, there is nothing to remark under this heading.

ROUGHING, FINISHING, SHEARING, OR SAWING OF PLATES.

Up to this point plates rolled either trough or flat have received much about the same treatment, but it will presently be seen that the two methods of rolling the slabs to plates are entirely different.

ROLLING OF FLAT PLATES.

When once an ingot has been thoroughly well compressed before leaving the cogging, the subsequent rolling into thin flat plates is an easy matter. The roughing rolls have collars and corresponding grooves turned on them, which entirely prevent any side play, as, even should the brasses at the neck of the rolls wear, one roll cannot move horizontally of itself. Such rolls are said to be "boxed." The top roll is usually about 2 inches larger in diameter than the bottom, by which means the plates, as they pass from the rolls, are made to bear downwards, instead of, as was often the case when the top roll was the smaller of the two, running up sometimes to the roof of the mill. The slab, when raised in the wash-heating furnace to the proper temperature, is brought to these rolls and further compressed in the four passes, until its section measures $13\frac{3}{4}$ inches by $\frac{1}{2}$ inch. It is then immediately passed through the finishing rolls, the last pass through which adjusts the plate to section and weight, at the same time rolling on it the name of the railway to which the sleeper belongs, that of the maker, and the date of manufacture. The length of a rolled bar is about 120 feet. The weight of sleeper-plates is a very important matter, and requires most careful watching. Plates rolled from slabs insufficiently heated are sure to be heavy; while on the other hand, if the slab has been overheated, the plates may be too light. An allowance of 3 lbs. either way on a

120-lb. plate is permitted, and should not be exceeded; but the Author has found that, with ordinary care, flat plates will not vary more than 2 lbs. either way on a plate of weight as stated above.

The thickness of the plate edges sometimes vary about $\frac{1}{8}$ inch, but this may easily be detected, as the thinner side of the plate, being also longer than the thicker, will assume a wavy appearance on leaving the rolls. This defect may be remedied by running cold water on to that portion of the roll which has produced the thin edge.

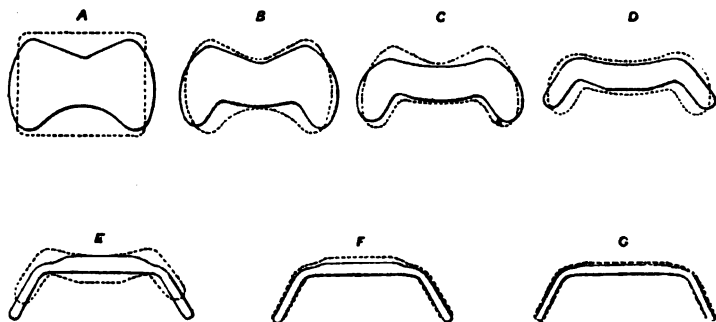
The weight of sleepers may often be adjusted to a nicety by the judicious use of cold water on the rolls.

The points to be watched are:—1. Width overall of plate; 2. Thickness of edges; 3. Weight per plate.

THE ROLLING OF PLATES IN TROUGH.

It will be remembered that the ingot from which trough-shaped plates are to be rolled, measures after cogging 8 by $6\frac{1}{2}$ inches at its

Figs. 6.



cross section. This ingot, or rather slab, when reheated, is passed through the roughing rolls and compressed, assuming in turn the sections shown at A, B, C, D, E, F, G, *Figs. 6.*

The great difference between the roughing and finishing rolls used in the manufacture of trough and those used for flat plates, is that the former cannot be "boxed" as the latter can, consequently one roll may move transversely independently of the other, any slackness in the fit of the brasses in the roll standards at once affecting the relative thickness of the two sides of the plate being rolled.

Suppose, for example, that a slab is, through unequal heating in

the furnace, somewhat softer on one side than the other, the colder, and therefore the harder, side offering more transverse resistance to the rolls will cause them to draw hard against the hotter and softer steel, and so result in an inequality in the thickness of the two sides often amounting to $\frac{3}{32}$ inch in the finished plate. This inequality is very detrimental to the proper shaping of the sleeper under the press, and frequently affects the position of the clips or jaws under the punchers, and has, in the Author's experience, been the cause of a very large number of rejections. Trough-rolled plates in cooling curve considerably, consequently their proper adjustment on the press block is very difficult, and in many cases impossible. The weight of plates rolled in trough varies considerably, frequently to the extent of 12 lbs. on a standard 120-lb. plate.

THE SHAPING OF STEEL SLEEPERS.

Steel sleeper plates, both of flat and trough section, are shaped while red hot under a hydraulic or steam press, to which are attached suitably shaped cast-iron moulds. Of these moulds, that forming the under or concave part of the sleeper is usually fixed to the bed of the press, while the upper block is bolted to the top table, which in turn is attached to the hydraulic ram and is movable vertically, the ends of the table sliding in grooves cast in the standards of the machine. The sleeper-plate having been placed in position on the bottom block, the top table and with it the upper block is lowered, pressing the plate on to, and folding it round, the bottom block. Besides shaping the sleeper, these blocks, whose wearing surfaces are chilled, give to those portions of the plate which ultimately form the rail-seats, an inclination of 1 in 20.

Formerly the bottom block was cast in two pieces, so that, if one end failed, it might be replaced without removing the whole block. This arrangement, however, gave rise at times to serious defects in the sleepers, for however tightly the blocks might have been bolted to the machine, the repeated shocks sustained when the heavy top block descended invariably caused the two halves to be moved out of line, marking the sleepers very badly; indeed, sometimes nearly shearing them in two where the blocks met.

Besides this, as soon as the blocks had become sufficiently slack to move transversely, they very soon also lifted slightly each time a sleeper was pressed, the result being that the scale from the plates, a large quantity of which is formed, worked its way under

the blocks and entirely altered their proper inclination, thereby spoiling the sleepers.

This never happens when the bottom block is cast in one piece throughout its length. The top block or mould may with advantage be cast in two pieces, and these should not be too rigidly fixed to the machine, as they readily adjust themselves to the plate which is being pressed; and in the case of trough-rolled plates, the thickness of whose sides often varies very considerably, this is a great advantage, as it relieves the ram of much of the side pressure brought on it by such irregularities of thickness.

So far as the shaping of steel sleepers is concerned, the Author is entirely in favour of sleepers formed from flat rolled plates, as it is very rarely that these vary more than $\frac{1}{4}$ inch, after shaping, measuring from the centre of plate outside or inside to the edges; while it is a very common thing to find, with sleepers formed from trough rolled plates, a variation of $1\frac{1}{2}$ to 2 inches, the disadvantage of which on the permanent way in time of floods is at once apparent. It is preferable to shear rather than to saw plates to length, as in the latter case a fin is left on the under edges, which is detrimental to the pressing of the sleepers and to the fingers of those who have to handle them. About ten sleepers of the metre gauge and six of the 5 feet 6-inch gauge can be pressed to shape and punched per minute.

THE FORMATION OF RAIL-FASTENINGS.

The most important of all the operations which take place in the construction of steel sleepers of the "inseparable clip" type is that of the formation by punching of the clips or rail-fastenings.

The life, and therefore the value of the sleeper itself, depends upon the strength of these fastenings, while the accuracy of gauge, or distance between the rails, is determined by their proper relative position. It is well known that if steel is punched either cold or at a low heat, the metal surrounding the punched portion is very injuriously affected; but that if annealing is afterwards resorted to, the strains set up in punching are to a certain extent removed.

Unfortunately it is not possible to anneal an article of irregular form and section, without its becoming distorted in cooling to such an extent that the amount of after adjustment required entirely precludes the possibility of the cheap and rapid manufacture of such an article. For this reason, steel sleepers cannot advantageously be punched cold and afterwards annealed. The only alternative, then, is to form the rail-fastening while the sleeper

plate is at a good red heat, and to complete the manufacture of each sleeper before its temperature has fallen to anything like a black heat. In punching sleeper-plates at a red heat, two difficulties present themselves; the first being that of maintaining a proper relative position between the fastenings, owing to the irregularity in the contraction of plates, either from the quality of the metal or variation of temperature at the time of punching; secondly, there is the difficulty of keeping the punches and dies, which constantly come in contact with the red-hot metal, sufficiently cool to ensure keen cutting edges, without lowering the temperature of the sleeper itself in the neighbourhood of the jaws.

Before dealing with these difficulties, the Author proposes to give the results of experiments which he carried out on a large number of sleepers, with the view of ascertaining the most suitable temperature for the formation of rail-fastenings of the type used on Indian State railways. The steel used in these experiments was uniform in quality, and of equal tensile strength.

1. Of clips punched in cold plates, 100 per cent. broke off short on being bent back with the usual testing spanner through an angle of 10° . 2. Of clips punched in cold plates which were afterwards annealed, 50 per cent. broke off at an angle of 20° , while 50 per cent. broke off at an angle of 90° . 3. Of clips punched in plates which had been heated to a bright cherry red and allowed to cool down to a black heat before being punched, 66 per cent. broke off short, while the remainder failed before reaching an angle of 30° . 4. Of clips punched in plates at a black heat and afterwards annealed, 91 per cent. bent back double on themselves, while the remainder stood to an angle of 90° before breaking. 5. Of clips punched in plates at a cherry-red heat, all clips bent back double, while the result of tests made on plates punched at a red heat and afterwards annealed was equally satisfactory.

These experiments show very clearly the danger of forming the rail-fastenings on a sleeper plate which has become too cold before reaching the punching machine, and the absolute necessity of punching the metal while at a good red heat.

Given the proper temperature, there are two methods of forming the rail-fastenings in a sleeper, each having its advantages. In the first, or direct, method, the clips are punched at once to their proper position, while in the second, they are punched deeper, and are afterwards brought back to their proper position by being hammered on to suitably shaped pieces of metal called drifts. The first is far the cheapest method, and, provided everything is satis-

factory, results in a good job; but, unfortunately, the quality of metal, condition of punches and dies, and temperature at time of punching, are constantly varying, and it is the Author's experience that clips formed by the second method, which ensures a sufficient root to the clip and the removal of fins or burrs left by blunted punches, are the most uniform and satisfactory both as regards strength and finish.

Returning now to the actual manufacture of a sleeper; on leaving the press, where it has assumed the required shape, it is immediately taken to the punching machine, turned on its back, adjusted to position, and the clips punched down, the latter being either drifted or not, according to method of manufacture adopted.

Some manufacturers secure accuracy of gauge in the sleeper by making distance marks on the sleeper plate, and by blowing steam on to it until these marks trammel correctly, when the clips are at once formed, or, if the distance marks are found to be near each other, the temperature of the plate is raised and the gauging again tested. Others again judge by practice the proper heat, and although from time to time, through carelessness, variations of gauge may arise, with proper care and attention on the part of the workmen, the gauge is sufficiently accurate for all practical purposes. About $\frac{3}{16}$ inch total variation is allowed by the terms of the specification, but the Author has noticed that platelayers make short work of adjusting a sleeper, which is either $\frac{3}{16}$ inch too wide or too narrow, to gauge. The most satisfactory method of keeping the punches and dies cool without injuring the sleeper plates themselves, is one in which jets of water impinge on the punches and drain on to the faces of the dies before running to waste. The water is started and stopped automatically by the rise and fall of the punches, the motion of which opens and closes the stop-cocks. As soon as the punches begin to descend, the water is cut off, and does not flow again until the punches have cleared the plate.

It has been found that by cooling the punches and dies in this manner, a saving of 60 per cent. is effected in the wear of the tools, while the advantage to the jaws of the sleepers is equally great.

COATING OF SLEEPERS.

Steel sleepers are usually coated with a mixture consisting of 3 parts coal tar and 1 part tar oil, which is kept in a boiling condition by the passage of the hot plates through it.

It is very essential that the sleepers should not be so hot at the

time of dipping as to cause the solution to give off thick suffocating fumes. The coating formed in this manner flies off like so much coal dust, and is of no use in preserving the sleeper from rust.

In conclusion, the Author makes the following suggestions as regards the manufacture of steel sleepers:—1. That the steel used in sleeper manufacture should not be of a higher tensile strength than 30 tons per square inch. 2. That tensile tests of the steel used should be made as often as possible; this test being the surest guarantee of the after behaviour of the metal in punching. 3. That sleeper plates should be rolled in the flat form in preference to the trough. 4. That, when possible, the sleepers should be pressed and punched immediately on leaving the rolls, care being taken that only such a number of plates are pressed as will ensure the last being at good heat after leaving the punching machine. 5. That the sleepers should in no case be dipped in tar at such a temperature as to give rise to thick yellow fumes. 6. That at least 2 per cent. of the rejected sleepers should be tested, and 3 per cent. weighed separately daily.

The Paper is accompanied by fifteen sheets of drawings, from which the *Figs.* in the text have been prepared.

(Paper No. 295.)

“Meters for recording the Consumption of Electrical Energy.”¹

By CHARLES HENRY WORDINGHAM, A.K.C., Stud. Inst. C.E.

THE rapid advance that electric lighting from central stations has made during the last few years has brought the question of the construction of instruments for recording the energy used by individual consumers into great prominence. The subject had engaged the attention of inventors for many years previously; but the need was not so pressing, and, numerous as had been the attempts, but few instruments had passed the experimental stage. Hence, the early supply companies were forced to charge their consumers a fixed price per annum based on an average number of hours of burning, such average being of necessity arrived at by guess-work in the absence of any experience. It was found that this system was unsatisfactory to the company and its clients, for in the case of clubs, restaurants and many shops, three hours—the average time assumed—was found to be absurdly small; and, on the other hand, it was too large for many private houses. Endless disputes resulted, and consumers became dissatisfied and ceased to use the light. A large amount of loss was occasioned by persons leaving lamps burning needlessly, because they had not to pay for them; and it is a significant fact that in the case of a large central station in London, the current during the day was sensibly diminished when a large number of consumers were supplied by meter instead of by contract.

The urgency of the demand for meters has brought forth a supply, and there are now in the market several types that are reliable and accurate, and the Author purposes confining his remarks chiefly to these, merely glancing briefly at a few of the best of the early and less successful types.

There are two fundamentally different systems of supply, i.e. (i) by continuous, and (ii) by alternating currents; and to each of

¹ This communication was read and discussed at a meeting of the Students on the 11th of December, 1891.

these belong certain classes of meter that will only work with a particular kind of current, while some are common to both systems; these last are usually dependent for their action on the square of the current.

In all cases it is desired to measure the total amount of energy that has been converted into light and heat in the consumers' lamps and wires, and a meter is an instrument that continuously records the power delivered, and integrates it with respect to time.

In the case of continuous currents, if E be the potential difference, or pressure in volts, between the mains at any instant, and C the current in amperes at that instant through the lamps, then $E \times C$ is the power, or rate at which energy is being supplied in watts; and if t is the time in hours during which the rate is kept up, then ECt is the total quantity of energy in watt-hours used by the consumer in the time t . This number divided by one thousand gives the number of commercial or Board of Trade units (B.T.U.) consumed. What the meter has to do, then, is to sum up the successive values of this product.

With alternating currents the measurement of the power is not so simple, for in this case if the mean pressure and the mean current be multiplied together, the product is not necessarily the power absorbed. If the current lags behind the pressure, as it will if the circuit possesses self-induction (and it always does so in practice, though in the case of a bank of incandescent lamps the lag is negligible), the current maximum does not occur at the same instant as the pressure maximum, and the real power is less than that obtained by multiplying together the mean pressure and the mean current. Taking the same units as before, if E be the maximum pressure, C the maximum current, and ϕ the angle of lag of the current behind the pressure,

$$\text{then the true power} = \frac{EC}{2} \cos \phi.$$

Since all distribution is effected at constant pressure, it is sufficient to integrate the current only, and to multiply the result by the pressure in the case of continuous currents, and of alternating currents also, if incandescent lamps only are in circuit; provided in all cases that the standard pressure is closely maintained. This course is adopted in a large number of meters, and is quite satisfactory in practice. If, however, greater accuracy be desired, the principle of the watt-meter must be employed. Here the stress between two coils, one of which carries the main current and the other a shunt current proportional to the pressure, is made

use of. The force in the case of continuous currents is proportional to the product of the pressure and current; but in the case of alternating currents this is only the case if the shunt coil has no self-induction, a condition manifestly impossible to obtain; it can, however, be sufficiently reduced to render the error very small.

It would be entirely out of place in a Paper of this kind, which aims at a description of actual instruments in commercial use, to enter into a mathematical discussion of the measurement of alternating currents, the matter being fully treated in textbooks in language far more able than the Author's, and to which he could add nothing.

Meters fall broadly into four classes:—

1. Those in which the current to be measured, besides controlling the registering gear, supplies the motive power for it.
2. Those in which the current to be measured controls the registering mechanism, while a separate current supplies the motive power.
3. Those in which the current merely controls mechanism which is driven by some force altogether external to the current, such as a spring or weight.
4. Those in which no gearing is driven, but chemical action goes on, involving an alteration in mass of a plate of metal.

CLASS 1.

Numerous forms of motor meter have been designed, and some of the most successful instruments in use at the present time are included in this class. The majority are current-, and not power-integrators, the pressure being assumed constant as already explained.

Ferranti Meter.—This depends for its action on the fact that when a mass of mercury is cut normally by lines of magnetic induction, and an electric current flows radially through it, the mercury tends to rotate. If the same current that flows through the mercury excites the field, the speed of rotation will be proportional to the square of the current; but mercury being a fluid, its motion is opposed by friction against the sides of the containing vessel with a force that varies as the square of the speed, hence the speed of rotation is proportional to the current. This principle is equally adapted to the measurement of continuous and of alternating currents, and it has received very great development at the hands of the inventor. It is the meter that is chiefly used by the London Electric Supply Corporation for

installations exceeding 40 amperes, and as the Author has had a large experience of it, a detailed description may not be out of place.

When the principle is applied to making a practical instrument, an aluminium fan, mounted on a spindle, is immersed in the mercury, and is carried round by it; the spindle carries a pinion gearing into a train of counting wheels. This counting mechanism introduces friction that is practically independent of the speed of rotation, and is greater when the meter is at rest than when it begins to move. The whole friction is thus made up of two parts, one varying as the square of the speed, the other independent of the speed; obviously the relative importance of the latter diminishes as the current, and therefore the speed, increases. In order to compensate for the error that would thus be introduced, a "shunt coil" is provided, i.e., a fine wire winding on the field magnet placed as a shunt across the lamp leads, thus establishing a certain magnetising force independent of the number of lamps alight. The relative importance of this magnetising force manifestly decreases as the main current increases, and this effect is enhanced by a transformer action being set up, whereby the main current generates in the shunt coil an electromotive force oppositely directed to that acting on it, thus further cutting down its magnetising effect. By suitably varying an extra resistance in series with the winding, the compensation can be made practically perfect. In Fig. 1, Plate 11, are plotted three curves that very clearly show the part played by the shunt coil. A constant current was maintained through the main coil, and the current in the shunt coil was varied by altering the extra resistance in series with it, the speed of rotation for successive values of the latter being noted. Another value was then given to the current in the main coil and the same operation repeated. The results are plotted for three main currents, revolutions per unit as ordinates, and extra resistance as abscissae. It will be seen that, except for very large shunt magnetising forces, the effect of the shunt coil at high currents in the main winding is small. The point in which the three curves cut gives the extra resistance required by the particular meter.

One of the latest forms of this meter is shown in Fig. 2, Plate 11. It is intended for a maximum current of 100 amperes, and with this load on for twenty-four hours does not rise to an excessive temperature. This, it may be noted in passing, is a point that should always be tried for each meter containing iron if intended for alternating currents, for it is found that out of a batch of similar

meters several will heat excessively. The cause is somewhat obscure, but is probably due to the laminations of the iron becoming short-circuited. The meter is contained in a well-ventilated brass case, A B C, no wood being used in its construction. The brass cylinder B is slipped on after the leads are fixed, and is secured by a wrought-iron pin D, passing through it and under the base; a small hole, E, is drilled through the end of this pin, and tape is passed through this and sealed. It is thus impossible for the meter to be tampered with, and the whole arrangement is very compact and convenient. The magnetic circuit F F is closed, except for the gap G, which contains the mercury. The current enters by the central portion H, the rest of the top and bottom of the cavity being [covered with vulcanised fibre. The circumference of the bath is uninsulated and by it the current leaves, flowing thence through the main coil K, one end of which is attached to the iron of the magnet, and so out of the meter. The shunt coil is shown at L and the extra resistance at M; N is the fan, wholly immersed in the mercury and carried by the spindle O which drives the train P.

The following is a test made of a meter of this type:—

TEST OF 100-AMPERE ALTERNATE-CURRENT FERRANTI METER.

Meter started with 0·92 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·5	10·4	7·5	17·5	40·0	16·9	80·0	17·3
3·0	15·4	10·0	17·0	50·0	17·0	90·0	17·3
4·0	17·5	20·0	17·0	60·0	17·3	100·0	17·5
5·0	17·3	30·0	17·2	70·0	17·3		

It will be noticed that the uniformity of the constant is most marked, and it has been found, after repeated experiments, that if the meter is adjusted so as to have the same constant at 10 amperes and 100 amperes, the value will be practically the same at all intermediate points.

In the continuous current form, solid cast-iron or steel is substituted for laminated wrought-iron, and the residual magnetism takes the place of the shunt coil.

The following are tests of two of these meters :—

TEST OF 100-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Meter started with 0·25 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·0	16·6	50·0	16·6
10·0	16·4	100·0	16·5

TEST OF 10-AMPERE CONTINUOUS-CURRENT FERRANTI METER. UNSHUNTED.

Meter started with 0·15 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.
1·0	110
5·0	112
10·0	110

An important point in connection with the permanent magnetism of these meters, which renders its use unobjectionable, is that the steel giving the initial field is magnetised to saturation by the largest current the meter is intended to carry, so that every time the full load is on the meter the steel is re-magnetised, and any danger of falling off in strength of field is avoided.

In the latest form, meters of the same capacity are made to have the same constant by adjusting the width of a gap in the magnetic circuit, and by the introduction of suitable gearing the constant is dispensed with and the meter is rendered direct-reading. These meters are "double-sealing," i.e. the working parts can be sealed by the local authority against any possible tampering by the supply company, while the latter can independently seal the terminals in order to protect itself from fraud on the consumer's part.

Some of these mercury meters have been at work for two or three years without any attention, though it is desirable to clean the trains and mercury once a year. The following case will give some idea of the constancy that may be attained by this kind of meter. The meter, an alternate-current one, was installed on the 3rd of

December, 1887, and removed on the 25th of February, 1890, during the whole of which time it received absolutely no attention. It was, however, read weekly, so that its performance could be noted, and was constantly at work, except for one week, when it was removed from one consumer's installation—the consumer having ceased to take light from the company—and placed in another's. During the period named the fan made rather more than 9,500,000 revolutions. The tests of the meter before it was put on the circuit and after it was removed are as follows :—

TEST MADE BEFORE METER WAS INSTALLED.

Meter started with 0·8 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
1·9	17·77	28·75	17·70
4·6	17·77	57·0	17·77
6·4	17·73	95·0	17·73

TEST MADE AFTER OVER TWO YEARS' USE.

Meter just failed to rotate with 2·17 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·2	14·58	70·0	17·83
20·2	16·63	89·6	17·81
50·2	17·93		

The increased current required to start the meter, and the diminished constant at low currents, are obviously due to the train requiring cleaning. The constancy at the high currents is most satisfactory.

Forbes Meter.—Another meter that is adapted equally to alternating and to continuous currents is that invented by Professor G. Forbes. It is based on the heating property of the current, and consists of a horizontal spiral of iron wire, over which is mounted, on a delicate pivoted suspension, a system of mica vanes. Convection currents are set up in the air by the hot wire, and these,

rising against the vanes, urge forward the ring on which they are mounted, its motion being registered by a train of counting wheels.

The standard form at present made has a maximum capacity of 30 amperes, and the heated conductor consists of two concentric wires connected together by a number of fine wires. The current enters at a point in the circumference of one circle, and dividing between its two halves, flows by the fine wires into the other, and leaves by a point in its circumference.

In order to increase the starting power of the meter, a small weight is attached to a cord passing over a pulley and round a drum on the last wheel of the train; this tends to drive the train, and so gives the vanes less work to do.

This meter gave great promise when it first appeared, but it does not seem to have met with much favour, probably because, resembling, as it does, a laboratory instrument in delicacy, it is found unsuitable for practical work. It is liable also to be affected by external changes of temperature and by the temperature of its case not being uniform.

Hookham Meter.—This consists of a motor driven by the current to be measured, the motor being retarded by eddy currents set up in a copper disk. A tungsten-steel permanent magnet with cast-iron pole pieces provides a constant field, and in this is placed the armature, which consists of flat coils laid on a copper disk, the latter serving the double purpose of a support for these coils and of a brake, the latter effect being produced by the eddy currents set up in it. The armature spindle rests on friction-wheels, so that a small force will cause it to move, and with a view to still further diminish friction, mercury contacts are provided, instead of brushes, for the commutator.

The theory of the instrument will be plain from the following considerations. The work done in a given time is proportional to the attraction between the disk and the field, and to the speed. Now in a constant field the electromotive force generated in the disk varies as the speed, and since this acts through a constant resistance, the eddy currents also vary as the speed; hence the work done is proportional to the square of the speed. The work supplied by the armature is proportional to the driving force and to the speed, but the driving force varies as the current; hence the work supplied in a given time varies as the current and the speed; but it has been shown that the work done is proportional to the square of the speed; hence it follows that the speed is proportional to the current.

The principle can be adapted to either alternating or continuous currents, but so far instruments for the latter class of current only have been constructed.

The meter is adjusted so that the dials show Board of Trade units, and it thus possesses the important advantage that its indications have not to be divided by a constant. This is brought about by varying the strength of the field in which the armature revolves, by short-circuiting more or less the magnetic circuit.

Some difficulty was experienced in passing the whole current through the mercury contacts, so that in the latest form all the motors are made to carry 5 amperes, and are shunted with a German silver resistance that allows the requisite proportion of current to pass. This is open to two serious objections, viz.: (i.) any error in the meter is magnified, since a portion only of the current drives the motor; (ii.) if the resistance of contact of the mercury varies (as it is almost certain to do), the motor does not get its right proportion of current, and its indications are therefore fallacious. The mercury being exposed to the air and being subject to sparking, is rapidly oxidised, and in practice much trouble is experienced on this account, the meter requiring, after a time, a considerable current to start it. The permanent magnet is also an objectionable feature, though it is said that little change is found to occur in the field on account of the care taken in the preparation of the magnets, and because the gap in the magnetic circuit is small.

The Author has not had the opportunity of testing any of these meters, but it is stated that a 20-ampere meter starts with 0.4 ampere; and that with 0.6 ampere the error is 25 per cent.; with 1.2 ampere it is 10 per cent.; while after 2.5 amperes the error is negligible.¹

Elihu Thomson Meter.—Another meter closely resembling this in principle has lately been developed by Professor Elihu

¹ Since this Paper was read, Mr. J. H. Tonge, Stud. Inst. C.E., has favoured the Author with the following test of a 100-ampere Hookham meter for continuous currents. With pure mercury in the contact cups, the meter started with 1 ampere, and with 100 amperes it read 1 per cent. low; with 50 amperes, 4 per cent. low; with 20 amperes, 9 per cent. low; and with 3 amperes, 17 per cent. low. When, however, ordinary commercial mercury which had been in use for a short time was substituted for pure, 3.5 amperes were required to start the meter, and with 100 amperes it read 8 per cent. low. This conclusively proves the statement made as to the error introduced by the variable resistance of the mercury contacts.

Thomson, and appears to be free from some of its defects. A motor is provided, having its armature wound with fine wire and excited with a shunt current, and its fields, without iron, excited by the main current. Since the field is proportional to the current, and the armature current to the pressure, the driving force is proportional to the watts, and hence the instrument is a watt-hour meter. The opposing force, as in the Hookham meter, is due to eddy currents, generated in a copper disk, which is rotated by the armature in a constant field set up by permanent magnets. It is thus open to one of the objections to that meter, but is free from the mercury contacts and variable shunt resistance.

Falling off in strength of the permanent magnets is much to be apprehended, since they are under peculiarly trying conditions: the eddy currents, as in the Hookham meter, tend to demagnetise the magnets; and in the alternating form they are subject to the mechanical vibration which always accompanies this class of current. Another source of error is the friction of the motor brushes, which is likely to alter with wear and dirt.

Time alone can show the importance of these objections; there can be no doubt that when new the meter is capable of giving indications of great accuracy, as the following test proves:—

TEST OF 25-AMPERE ELIHU THOMSON METER.

Meter started with 0·4 amperes.

Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.	Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.
24·9	100	2,490	10·14	10·9	100	1,090	9·78
23·9	100	2,390	10·02	9·7	100	970	9·78
22·9	100	2,290	10·02	8·6	100	860	9·84
21·9	100	2,190	10·08	7·8	100	780	9·84
20·9	100	2,090	10·02	6·8	100	680	9·72
19·8	100	1,980	10·02	6·0	100	600	9·72
18·8	100	1,880	9·96	4·8	100	480	9·72
17·9	100	1,790	10·20	4·0	100	400	9·60
17·0	100	1,700	10·20	3·0	100	300	9·42
15·9	100	1,590	10·02	2·0	100	200	8·70
14·9	100	1,490	9·96	0·99	100	99	7·44
13·9	100	1,390	9·96	0·78	100	78	6·66
12·9	100	1,290	9·90	0·58	100	58	4·98
11·9	100	1,190	9·90				

In order to try the effect of varying the pressure as well

as the current, the following tests were made of the same meter:—

Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.	Current in Amperes.	Pressure in Volts.	Power in Watts.	Revolutions per Board of Trade Unit.
24·8	108	2,678	9·96	24·9	90	2,241	10·14
20·1	108	2,171	9·96	20·1	90	1,809	10·02
15·2	108	1,642	9·72	14·9	90	1,341	9·66
10·0	108	1,080	9·66				

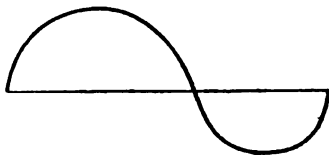
The extremely low speed of the armature, and its property of stopping almost dead immediately the current is switched off, are noticeable points, and the former is an important advantage, as tending to lengthen the life of the meter by diminishing the wear.

In measuring currents supplied on the three-wire system, the neutral wire does not enter the meter, but the others pass each through one of the two field-coils. The armature circuit is connected across the outer conductors, being thus excited with 200 volts.

When it is desired to measure the current conveyed by the high-tension mains from an alternating central station, the high-tension lead is taken through the field-coils, while the armature circuit is excited by the secondary of a special converter, having its primary connected across the high-tension mains.

Ferranti-Wright Meter.—This is, in effect, an alternate-current motor, and depends for its action on one of those peculiar phenomena which take place when a conducting circuit is cut by lines of magnetic induction which are varying rapidly in direction and intensity. The meter is shown in plan diagrammatically in Fig. 3, Plate 11. The four limbs A B, B D, D C, C A, consisting of laminated wrought-iron, are wound so that B and C are opposite poles; each of these is fitted with a pole-piece consisting of an elongated horn, forming part of a circle within which is placed a conducting disk E, usually, but not necessarily, of iron. Each horn is surrounded by a closed conducting circuit of low resistance, consisting of one or more copper bands slipped over them, shown at F F. It is impossible to give a full explanation of this remarkable meter in a few words, but perhaps the following will make its principle fairly

clear. Suppose a current to rise in the magnetising coils from zero to a maximum, then it tends to magnetise the iron, and the induction in the iron follows the successive values of the current in the part enclosed by the coils nearly instantaneously, but in the horns it lags behind the current, partly on account of hysteresis, but chiefly because its change generates in the circuit F F currents that tend to magnetise the iron in the opposite direction. The action of the closed copper circuit is to hinder the rise of magnetism in the iron, giving it a kind of magnetic self-induction, in just the same way as iron gives to an electric circuit ordinary self-induction. Now suppose, for a single rising current, there be substituted a rapidly alternating one, then any point in the horn will experience a series of waves of magnetism following one another, and successive points along the horns will be subject to waves of diminishing amplitude (for the maximum induction falls off towards the tips), differing in phase from one another on account of the lag above mentioned. The state of the induction in either horn at any instant may be represented by a curve such as is shown



in the diagram, the lag being sufficiently great in some cases to cause the induction to be of opposite sign at the tip and at the root. There are thus as it were a series of tufts of lines of force travelling along the horns and brushing past the disk. Now these induce currents in the disk, and, owing to its self-induction, the repulsive effect preponderates over the attractive, and the disk is repelled round. It is found that its speed is proportional to the square of the current, but, by mounting radial mica fans on it, its motion is retarded by the air-resistance with a force that varies nearly as the square of the speed, and hence the disk revolves proportionately to the current. There are two causes operating to disturb this proportion at the two ends of the range : (i.) At starting, the friction of the disk spindle is relatively large, and the speed is lower than it should be; this is overcome by winding the magnets with a shunt coil that is just sufficient not to cause the disk to revolve. (ii.) At high speeds the air-resistance depends on a rather higher power than the square of the velocity, thus making the speed somewhat lower than it should be. This is compensated for by slitting the fans as shown in Fig. 4, Plate 11, so that they yield somewhat, and thus expose a less effective surface. How perfect this compensation is, may be judged from the following tests of a 10-ampere and 20-ampere meter :—

TEST OF 10-AMPERE FERRANTI-WRIGHT METER.

Meter started with 0.25 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.
1.25	117.0
5.00	116.4
7.50	115.2
10.00	114.0

TEST OF 20-AMPERE FERRANTI-WRIGHT METER.

Meter started with 0.65 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Reformation per Board of Trade Unit.
2.5	117.3	12.5	115.2
5.0	116.1	15.0	116.2
7.5	114.3	17.5	114.5
10.0	114.9	20.0	116.4

The beautiful simplicity of these meters, which have practically nothing to get out of order, has made them a most valuable acquisition, and they are almost exclusively used by the London Electric Supply Corporation for installations up to 40 amperes. They have proved to be reliable, and give practically no trouble as regards repairs; they are moreover light, compact and easy to instal.

In the latest form of these meters it has been found possible by great care in manufacture, to so diminish the friction as to render the shunt winding unnecessary. The field-magnets consist of two vertical limbs with horizontal curved horns embracing the armature; the horns are made movable, so that their distance from the armature can be varied, and the instruments adjusted to have the same constant. They are then rendered direct-reading by proportioning the gearing. The meters are "double-sealing," and the plate protecting the terminals covers also a small screw that admits of the armature and spindle being raised from the jewel during transit, without interfering with the Local Authority's seal. A minor point of difference from the older type is the substitution of aluminium for mica fans.

The following is a test :—

TEST OF 10-AMPERE FERRANTI-WRIGHT METER. UNSHUNTED.

Meter started with 0·4 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
10·0	240	3·0	240
9·0	238	2·0	238
8·0	242	1·0	224
7·0	247	0·8	209
6·0	240	0·6	193
5·0	238	0·4	198
4·0	243		

The unshunted form of this meter is very suitable for recording the quantity sent out through the high-tension mains of a central station, and it has been applied to this purpose.

Shallenberger Meter.—Like the last, this is an alternate-current motor. It consists of two coils with their axes set at an angle of 45° to one another, both surrounding a horizontal iron disk, free to revolve on a vertical axis; the plane of the disk is at right angles to the planes of the coils. One of these coils carries the current to be measured, the other is simply closed on itself. The current in the former induces in the latter a current which is a quarter of a period behind itself, and the effect of this is that the induced current, reversing as it does with the inducing current, attracts the poles successively set up by the latter, so producing continuous rotation. The motion is retarded by aluminium fans. The following is a test of a 100-ampere meter :—

TEST OF 100-AMPERE SHALLENBERGER METER.

Meter started with 3·5 amperes.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
5	13·0	50	13·3
10	12·8	55	13·1
15	13·1	60	13·4
20	13·3	65	13·3
25	13·3	70	13·3
30	13·0	75	13·3
35	13·3	80	13·1
40	13·3	85	13·1
45	13·3	90	12·5

It will be observed that the constant is remarkably good, but the starting power is distinctly poor.

A test of a smaller size is appended :—

TEST OF 10-AMPERE SHALLENBERGER METER.

Meter started with 0·4 ampere.

Current in Amperes.	Revolutions per Board of Trade Unit.	Current in Amperes.	Revolutions per Board of Trade Unit.
0·6	17·9	5·8	18·1
1·0	17·7	7·0	18·6
1·9	18·5	8·2	17·9
2·9	18·0	9·0	17·5
3·9	18·0	10·0	17·6
4·9	17·9		

Although the above results are given in the form of a constant, the meters are direct reading, the adjustment to identical constants being effected by altering the angle between the planes of the closed and inducing coils. The latest form is arranged to be "double-sealing."

This meter is very largely used in America by the Westinghouse Company, and in London by the Metropolitan Electric Supply Company. The London Electric Supply Corporation has also a few in use, with satisfactory results.

Slattery Meter.—This depends on the same principle as the Shallenberger, but differs from it in having a light copper cylinder in place of the iron disk, and in the way in which the motion of the revolving cylinder is retarded. Each vane consists of two quadrants of a circle A B C, A D C (see Fig. 5, Plate 11), the lower being pivoted about the centre A; it has attached to it an arm E weighted at F. When the speed increases, the weight flies out and raises the quadrant A C D, which slides behind A B C, thus reducing the surface exposed to the air-resistance. This is a different way of accomplishing the result obtained in the Ferranti-Wright meter by slitting the fans.

CLASS 2.

Hopkinson Meter.—One of the earliest practical forms in this class is that invented by Dr. J. Hopkinson, M. Inst. C.E., and, probably, if the present demand had existed at the time at which

it was brought out, it would have received considerable development. This meter is shown diagrammatically in Fig. 6, Plate 11. A high-resistance motor A is placed as a shunt across the lamp leads, and is so arranged that when excited it causes a pair of governor balls B B to rotate; the centrifugal force of these tends to raise an iron core C, which is attracted downwards by the main current passing through the solenoid D. The core carries a contact E, which makes and breaks the motor circuit, and is so adjusted that when no current flows through the solenoid the circuit is broken. Directly a lamp is turned on, the core is attracted downwards and the motor revolves, increasing its speed until the governor balls cause its circuit to be broken. Now the centrifugal force is proportional to the square of the speed, and the attraction of the solenoid for the core is, within certain limits, proportional to the square of the current, hence these two forces will exactly balance, and the motor will revolve with a speed proportional to the current, for, if it rises above the proper speed, its circuit is broken and the speed falls, and if it falls below its right value, its circuit is made and its speed increases. The number of revolutions are recorded by a train of counting wheels driven by a worm from the motor spindle.

Frager Meter.—This is, perhaps, the most successful of this class of meter. It is an improvement on an earlier form known as the Caudray, and consists essentially of the combination of an ammeter or wattmeter, a clock and an integrating device connected to a system of counting wheels. The meter is adapted to either alternating or continuous currents—the wattmeter being always used in the former case. Its latest form may be thus described:—The movable coil of the wattmeter is of German silver wire wound on a wooden bobbin, a noticeable point being that, contrary to the practice of most makers, the whole of the shunt circuit is wound inductively and is movable, instead of only a comparatively small portion being so wound and the rest of the circuit formed of a non-inductive extra resistance. The coil is suspended by a wire of phosphor bronze, and carries a long lever, formed of aluminium in the larger sizes and of brass in the smaller, balanced with a brass counterpoise so as to hang horizontally. The end of this lever is furnished on its under side with a wedge-shaped piece of steel, and hangs over a horizontal cam or snail, shown in Fig. 7, Plate 11, which is kept in slow rotation by means of a ratchet-wheel worked by a pawl from a balance wheel, maintained in oscillation by a shunt current. The snail is carried by a cradle, hinged at A B (Fig. 7), and pressed upwards by a spring. Rigidly attached to

the spindle carrying the snail-cradle, and running along the straight edge of the snail and projecting beyond it, is a piece of steel C D, bevelled on its edge, which is circular, having the suspension wire for centre. As the spindle rotates, this bevelled edge comes in contact with the steel wedge on the lever, and causes the latter to rise and to jam against a brass sector placed over it. If no current passes through the main coil of the wattmeter, the lever stands at zero, and, as rotation proceeds, it simply drops off the piece C D. If, however, the lever is deflected when the engagement takes place, the lever drops on to the snail, depresses it, and causes a pawl E which it carries to engage with a ratchet-wheel, which ratchet-wheel drives a counting-train. Rotation goes on, and, as long as the lever remains on the snail, it is locked, and the counting-wheels continue to register. As soon as the lever reaches the round edge of the snail it drops off, the snail rises, and the pawl ceases to drive the counting-train. Now an inspection of the snail will show that its shape is such that the greater the deflection of the lever at the instant of its engagement, the longer it remains on the snail, and that it must drop off once every revolution. The action of the instrument is, therefore, this: at equal intervals of time, this interval being the time taken by one complete revolution of the snail (two hundred, three hundred, or four hundred seconds, according to the size of the meter) the lever is locked in the position which it happens to occupy at the instant, remains on the snail for a time proportional to its deflection, and then quits it, having caused a certain amount to be registered on the dials. Now this amount is that which would have been used in the time occupied by one revolution of the snail, if the current had retained the value it had when the lever engaged. If the current changes, no account is taken of the alteration until the next time the lever engages, when the current is again assumed to remain constant during one revolution. What the instrument does, then, is to take a reading of the wattmeter so many times an hour, to multiply each reading by the time of one revolution, and to add all these successive products together on the dials.

The following are details of the several parts:—

The balance wheel is furnished with a flat chronometer spring, and consists of a nearly complete circle, formed of two pieces of soft iron A A, Fig. 9, Plate 11, united by a brass piece, B. A short solenoid C excited by a shunt current, is so placed that when the wheel is at rest the soft iron cores are unsymmetrically placed. At the top of the spindle carrying this wheel is the contact

making device shown in Fig. 10, Plate 11. Two little steel plates, one above the other, shaped as shown, are mounted loose on the spindle; the top one has a V-shaped slot A, in which works a pin B attached to the spindle C, from which it derives an oscillating motion; the lower plate has a much wider V-shaped groove, shown dotted, and in this works a pin projecting downwards from the upper plate. Each plate has a depression, shown at D, and a knife-edge E fixed to a spring F, one end of which can make contact with a contact-screw G, bears against the plates. When the depressions in the two plates are opposite the knife-edge it drops in, and contact is made at G, completing the circuit through the solenoid. If the amplitude of vibration is small, the depressions in the two plates correspond; but if it becomes large, the lower plate is carried round by the upper one, and left so that it prevents the knife-edge from falling. When the amplitude diminishes, contact is again made and a fresh impulse given.

The counting-gear is connected to the snail-spindle by means of a pair of bevel-wheels, and by adjusting the number of teeth in them the meters are made to indicate Board of Trade units on the dials, however much the constants of the wattmeter may vary.

This meter is certainly ingenious, but evidently highly complicated. When carefully adjusted and protected from vibration, it is capable of giving accurate results with a steady current; but under the conditions of actual practice it labours under disadvantages, among which may be mentioned:—

(i.) The necessity for careful levelling and adjusting *in situ*, thus making it uncertain whether the test made before it is sent out will apply when it is installed in the consumer's house.

(ii.) So many working parts are liable to get out of order.

(iii.) In cases where the amount of light used is constantly varying at short intervals of time, as in a theatre, indications far from the truth may be given. Small variations in current, due to unsteady running, will cause the lever to oscillate, and it may therefore become locked at the wrong point.

Richard Frères Meter.—Like the Frager, this is an intermittent watt-hour meter; but it has this important advantage—its readings are separated by intervals of only fifteen seconds. It comprises a clock, wound electrically four times a minute, a wattmeter, and a train of counting wheels. The following cycle of operations is gone through every fifteen seconds. At a given instant a shunt circuit is made through an electro-magnet, the armature of which is attracted and winds the clock, the circuit being immediately broken again. After ten seconds another shunt

circuit is closed, causing a current to flow through the movable fine wire coil of the wattmeter and through an electro-magnet actuating a friction clutch. This clutch, under normal conditions, mechanically connects the movable coil with the counting train, but when pulled back it allows the coil to move without affecting the train. When the contact is made the clutch moves first, its moment of inertia being much less than that of the wattmeter; the coil then deflects, a dash-pot steadying it quickly; the current flows for five seconds and is then interrupted, the clutch flies back by means of a spring and the wattmeter returns to zero, carrying with it the first wheel of the train through an angle corresponding to its deflection. The clock-winding contact is again made and the same series of operations gone through as before.

This meter is in use in France, but has only recently been introduced into England; it is at present only used for continuous currents, but will doubtless soon be applied to alternating currents also. The Author has had no experience of the meter, but the number of contacts and the complication of its parts will probably be found serious drawbacks.¹

CLASS 3.

The majority of the meters in this class are founded on Professor Ayrton's ergmeter, which consisted of two clocks regulated to keep exactly the same time. One of these had a magnet in place of a bob at the end of the pendulum, and beneath it was placed a coil carrying the current to be measured; the magnet being attracted by the coil when the current flowed through it, the pendulum was accelerated, and the clock gained. The difference in time of the two clocks was thus a measure of the quantity of electricity that had passed. There have been numerous improvements on the original idea, the chief being embodied in the Aron and Oulton-Edmundson meters.

Aron Meter.—In this the two clocks are enclosed in one case, and their wheel-trains are connected to a differential gear, consisting of two bevel wheels, one driven by each clock. Between these, and gearing into both, is a bevel wheel free to revolve at one end of a spindle, the other end of which carries a counterpoise; to the middle point of this spindle, and at right angles to it, is rigidly

¹ This instrument must not be confounded with the Richard Frères recording ammeter, which is a very satisfactory piece of apparatus for a different purpose and hardly comes within the scope of this Paper.

fixed a second spindle connected to a counting train. If the large bevel wheels both revolve at the same speed, the intermediate wheel simply revolves on its axis; but if one goes faster than the other, the intermediate wheel, in addition to revolving, rolls on the large wheels by an amount depending on their difference in speed, and in so doing twists the counting spindle.

This meter is made in two forms, viz., (i.) that just described in which the pendulum carries a magnet; this is adapted to measure continuous currents only, and is a current integrator: (ii.) that in which the magnet is replaced by a fine wire coil oscillating inside a solenoid; this is adapted to either continuous or alternate currents, and is a watt-hour integrator. The former is in very extensive use, and all employing it speak highly of its performance. It is open to the objection already referred to in connection with the Frager meter, that it has to be adjusted *in situ*, for it is a fact well known to clockmakers, that a clock once shifted always requires regulating, no matter how carefully it may have been moved. The permanent magnet is liable to change, and it is found necessary to redetermine the constant of a meter that has been in a house where a short circuit has occurred, the magnet being weakened by the excessive current. The clocks have to be wound up at least once a month, and if one of them by any mishap should stop, the whole record is destroyed. It is the practice in some central stations to synchronise the meters every three months; it is then found that about half are slow and half fast, but the error is not serious. An evidence of accuracy is afforded by a meter at the station agreeing with the sum of the readings of the consumer's meters within, it is stated, a small percentage.¹

The second form is seldom used except for alternating currents, and with these it is extremely difficult to get an accurate test in the lower part of the scale, on account of the great length of time required in order to get a reading and the necessity for having the pressure and current observed during the whole run, since it cannot be relied on to remain steady as in the case of continuous current where cells can be used. The following is a test of the higher part of the scale of this type:—

¹ Since this Paper was read, the Author has been favoured by Mr. J. H. Tonge, Stud. Inst. C.E., with the following test of a 100-ampere continuous current Aron meter. The instrument read $\frac{1}{4}$ per cent. low with 100 amperes, with 50 amperes, and with 20 amperes, and 10 per cent. low with 1 ampere. In forty-eight hours the difference in time between the two pendulums was one complete period.

TEST OF 200-AMPERE ALTERNATE-CURRENT ARON METER.

Current in Amperes.	Pressure in Volts.	Board of Trade Units per Division.	Current in Amperes.	Pressure in Volts.	Board of Trade Units per Division.
200·1	100	1·071	120·0	100	1·070
190·2	100	1·081	110·3	100	1·055
180·0	100	1·075	100·0	100	1·057
171·0	100	1·101	90·3	100	1·056
159·7	100	1·063	80·0	100	1·102
150·0	100	1·068	70·0	100	1·083
140·3	100	1·065	60·0	100	1·068
130·0	100	1·066			

The meters are now made direct-reading, and are provided with an attachment for keeping the clocks in synchronism when no current is on, the difficulty in ensuring this being the chief objection to the meter. It is extremely simple, consisting merely of a light, very slack thread joining the two pendulums and having a small weight hung at its middle point. It effects its object perfectly, but it would appear probable that the constant at low readings would be altered. The Author has not yet tried whether this is the case or not.

A most ingenious modification has been introduced into this meter by Mr. Miller of the Kensington and Knightsbridge Electric Light Company. He employs only one clock which drives a soft iron disk through the differential gear already described. The disk revolves in front of a coil carrying the current to be measured and is retarded by it. This admirable device does away with the whole trouble of synchronising, as there is only one clock, and prevents the danger of the record being destroyed by one clock stopping. There should be an excellent future for this meter.

An adaptation of the Aron meter, made by the same inventor, supplies a great want felt by users of secondary batteries, viz., an indicator of the amount of charge in the battery. Now it is obvious that if the main current be reversed in the watt-meter form, repulsion will ensue and the pendulum will be retarded, the meter, in consequence, registering backwards. Mr. Miller found that, with the ordinary form of coils, if the current was reversed, the indications were not accurate, owing partly to the slow speed. He accordingly altered the form of the coils and shortened the pendulums, and in this way he succeeded in producing a meter that would register accurately whichever way the current flowed. In order to ascertain the condition as to charge of a secondary battery, he charges it fully through this meter, and

notes the quantity registered; the battery is then allowed to discharge through the meter, and the instrument goes back. When the time for recharging arrives, all the attendant has to do is to keep on the charging current until the meter shows its original reading. In this way the exact state of the battery is shown by an inspection of the meter.

The Richard Frères meter has been adapted to the same purpose by so mounting the fine wire coil that it can deflect on either side of its position of rest, thus driving the counting train either way according to the direction of the current. It has also been arranged that if a fixed loss in the battery be assumed, it can be allowed for by inserting a resistance in series with the fine wire coil when charging, thus making the meter register only the percentage of the charging current that will be returned.

Oulton-Edmundson Meter.—In this the ordinary pendulums are replaced by horizontal balances oscillating at about one-quarter the speed, the torsion being supplied by a straight flat spring which also serves as a suspension. The two clocks are driven by one mainspring. The controlled pendulum carries two fine wire coils, one swinging within the main coil, and the other above it. Each of the movable coils consists of two circuits, one placed across the lamp leads in the ordinary way, the other forming a shunt across the main coil; the small current passing through this second circuit is stated to be required in order to raise the constant at the higher readings. This meter in its present form has only recently been introduced.

Kelvin Meter.—One of the latest additions to this class of meter comes from the hands of Lord Kelvin, the inventor who has produced so many electrical measuring instruments of unsurpassed accuracy. As a laboratory instrument, no doubt the meter about to be described is extremely accurate, but it may be doubted whether it is suitable for practical use. In the first place, it is somewhat unreasonable to expect a consumer to descend every day to his coal-cellar, it may be, in order to wind up an instrument of which he is, in all probability, afraid and looks upon as some infernal machine. Next, it has working parts of extreme delicacy and is unsuitable to put into the hands of an ordinary linesman. Lastly, it is preferable to have a continuous, rather than an intermittent, integrator.

The instrument is a combination of a weight-driven clock which automatically breaks the circuit when it requires winding, an ampere balance and an integrating cam. A fixed coil carries the main current, and in front of it is placed a fine wire coil

carried at the end of a vertical aluminium lever free to turn on knife-edges about a horizontal axis. The lower end of this lever has attached to it a train of counting wheels, the first one of which can roll on a cylindrical cam which is kept revolving at a constant speed by means of the clock. When a current passes through the main coil the other is repelled, and the rolling wheel, which originally stood clear of the cam, moves over it, is raised by it, and rolls on its surface, thus actuating the counting wheels. Now the cylindrical surface of the cam is cut away screw fashion, so that, when at one end of it, the wheel only rolls for a small portion of its revolution, and at the other, remains on it for the greater part of a revolution, the time it remains on being proportional to the current corresponding to the position of the lever. A series of grooves are cut on the surface of the cam so that, once engaged, the wheel cannot shift sideways. A scale is provided over which the lever moves, enabling the instrument to be employed as an ampere gauge and its indications to be checked. The constant of the instrument can be altered so as to adapt it to various currents, by altering the weight on a horizontal rod projecting from the movable arm, and by altering the height of a nut on a vertical screw.

CLASS 4.

Edison Meter.—This is a meter adapted to continuous currents only, and depends for its operation on the electrolytic action of the current. A definite portion of the current to be measured is shunted through a bath containing a solution of zinc sulphate, the electrodes being of amalgamated zinc. The meter in its latest form contains three essential parts:—(i.) the electrolytic cell and compensating coil, (ii.) the shunt resistance, and (iii.) a device for keeping the electrolyte from freezing. The case of the meter is of well-seasoned hard wood, specially prepared to exclude air and to secure good insulation, and its front is closed by a substantial sheet-iron door.

(i.) The cell. This is of bottle form, and is covered to avoid evaporation. It is partially filled with a 10 per cent. zinc sulphate solution in which are suspended zinc plates supported by screws and nuts on ebonite distance pieces, connection being made to them by copper rods held by spring clips. The plates are prepared by being first thoroughly cleaned, then covered on the top and for a short distance up the rod with asphalt varnish and, lastly, amalgamated and dried. The positive plate is weighed before being immersed. The size of the plates is regulated by the

maximum current the meter is intended to carry, the quantity of zinc allowed for being at the rate of 150 milligrams per month for every ampere of nominal capacity. If the meter is likely to run at its full load for a large number of hours during the day, a larger cell is required than the above amount would give. In calculating the quantity that has passed through the meter, one ampere flowing for one hour is taken as depositing 1,224 milligrams of zinc. The counter-electromotive force of the cell decreases as the temperature rises, and its resistance also falls; in order to compensate for the error thus introduced, a copper coil, the resistance of which of course increases with the temperature, is placed in series with the cell, and is so adjusted that the effective resistance of the combination is identical at 50° Fahrenheit and at 86° Fahrenheit, varying about 1 per cent. between these two points. As regards the change of effective resistance with change of current, it is found that the increase in counter-electromotive force is about compensated for by the fall in resistance of the cell.

(ii.) The shunt resistance is of German silver, and has such a value that $\frac{1}{175}$ th part of the whole current flows through the cell. The resistance of this material varies 1 per cent. for every 45° Fahrenheit change in temperature, and the maximum temperature attained by the meter is about 120° Fahrenheit; hence the error from this source does not exceed 2 per cent.

(iii.) The cell is kept from freezing by means of an incandescent lamp placed in the case of the meter and automatically lighted by means of a thermostat when the temperature falls below a certain value. This portion of the apparatus consists of a compound metallic strip which alters its curvature when the temperature falls, completing the circuit through the lamp. The contact point is carried by a screw having a pitch of $\frac{1}{8}$ -inch, with a hexagon head, the faces of which are numbered. In this way the temperature of contact can be adjusted to within 2° Fahrenheit.

A curve given by Mr. W. J. Jenks, in a Paper on this meter, read before the American Institute of Electrical Engineers, shows that after 3 amperes the rate of deposit is absolutely constant up to 20 amperes; the meter having, therefore, a sevenfold range, and registering with the smallest current, the error is in favour of the consumer.

The chief objections to this meter are:—the remarkably small fraction of the current that is measured—any error, either in deposit or in weighing the plates, being multiplied nearly a thousandfold; the necessity for the consumer relying entirely upon the good faith of the supply company for the accuracy of his

account—it being absolutely impossible for him to check his consumption from day to day, or to ascertain for himself the amount registered by his meter; and the constant attention required—the plates having to be removed every month, weighed and replaced.

This meter is in extensive use in America, and was used with satisfactory results at Eastbourne before the system was changed to an alternating current one; it has not, however, met with much favour in this country.

Lowrie-Hall-Kolle Meter.—This meter attempts to apply the electrolytic method to the measurement of alternating currents, and was worked out by the three inventors whose names it bears when they altered the system at Eastbourne from continuous to alternating, the Edison meter having given, as already stated, satisfaction in the former case. In series with the converter is placed a secondary cell, giving a pressure of 2 volts, and an electrolytic bath; the effect of this is to raise the positive wave bodily by 2 volts, and to diminish the negative wave by the same amount, the effect being the equivalent of 2 volts always acting in one direction through the circuit—the current flowing being proportional to the number of lamps turned on. The whole current thus passed through the secondary cell, but, so far from it having any ill effect, it seemed to prevent sulphating. It was found that in a suitable electrolytic solution, any metal can be by this method deposited by an alternating current, and the quantity so thrown down used as an indication of its amount.

Improvements in other types of meter prevented this being brought to a state of perfection in spite of its being fairly promising. It was, however, open to at least one serious drawback, namely, if the alternating current was switched off, and any lamps left turned on, the cell discharged through them and caused a registration to be effected in the electrolytic bath; moreover, the secondary cell had to be recharged every three months, and there can be little doubt that the inventors would have had trouble with the direct electrolytic action of the alternating current, for it has been shown that without any secondary battery being in circuit, such a current will cause deposition of an uncertain amount, depending on the size of the electrodes.

TESTING OF METERS.

In the commercial employment of meters, an important matter is their efficient and rapid testing; and it may be of some interest if the Author describe the arrangements designed and used by him

for testing the meters employed by the London Electric Supply Corporation. Their system being an alternating one, only meters adapted to this class of current are provided for. The kinds used are Ferranti mercury, Ferranti-Wright and Frager.

The method adopted in testing the mercury meters is to string a number together with their main coils in series with one another, and with an adjustable non-inductive resistance the shunt coils being connected in parallel across the converter terminals.

It may be well here to call attention to a source of error that is likely to be overlooked in testing any kind of shunted meter. When in use, the shunt coil has one end attached to the shunt terminal and the other to the converter end of the series coil. If the meters be connected in series, each being allowed to feed its shunt in the ordinary way, two errors will be introduced, as an inspection of Fig. 11, Plate 11, will show—(i.) With large currents in the series coils, the shunt of the meter nearest the converter is the only one receiving its full pressure (100 volts); the second has a pressure that is less than the 100 volts by an amount equal to the drop of pressure in the first; the third is deficient by the drop in two meters, and so on, the last of a long series receiving much less than 100 volts. (ii.) The last meter is the only one that has flowing through its series coil the current that is measured; the last but one receiving in addition to this the shunt current of the last; the third from the end those of the last two; and so on to the one nearest the converter, which receives in addition to the measured current, the sum of all the shunt currents of the other meters. These two errors are easily and completely disposed of by running a separate lead from the converter to excite them, as shown in Fig. 12, Plate 11.

To resume, the reading of the dials having been noted, the desired current is thrown on, and kept on for a time sufficient to obtain a reading of such a magnitude that an error of ± 0.1 would not affect the constant more than 1 per cent. It is then thrown off, and the reading is taken when the meters have come to rest. The number of revolutions per hour shown by the dials having been calculated from the difference of the readings, it is divided by the product of the current and the pressure; this gives the number of revolutions per watt-hour, and, when multiplied by one thousand, the "constant"—i.e., the number of revolutions—per Board of Trade unit. The pressure, and therefore the current, is maintained constant within one-half per cent., by the means described below.

Obviously there is a slight error in this method owing to the

meters requiring time to get up speed, but this is compensated for in practice by their taking approximately the same time to slow down after the current is removed. When the current is so small that the time required for a run is inconveniently long, the meters are allowed to attain their full speed with that current and the centre hands are counted, the number of revolutions at the end of 1, 2, 3 . . . minutes being noted. With practice, it is easy to estimate to the tenth of a revolution, and these meters revolve with such remarkable regularity that repeated experiments have shown it to be quite safe to infer the constant from a two-minutes count. The rate per hour of the dials having been calculated, the constant is found as before. This meter, as has been shown, has so smooth a curve that it is sufficient to adjust it at two points, one being that of maximum current and the other one-tenth maximum.

The Ferranti-Wright meters are tested in exactly the same way as the last, except that the first method is always used, the centre needle never being counted. Three points are usually determined in the curve, one being the maximum current, one about one-seventh maximum, and one midway between the two.

The Frager meters also are strung in series, and the same precautions observed as regards exciting their shunts, but their different nature requires a different method of testing. There are two stages:—(i.) In the first the clock motor is timed and adjusted until it beats seconds within 2 or 3 per cent. (ii.) The meter as a whole is tested. The dials being set to zero, and the snails being in such a position that the levers have just left them (this is to allow them to become steady before engaging with the snails), the desired current is thrown on and the pressure, and therefore the current, kept constant within $\frac{1}{2}$ per cent. until the snails have made six complete revolutions. When the lever of the slowest meter has left the snail, the current is taken off and the readings are noted. The known percentage errors of the clocks having been allowed for, the number of Board of Trade units that would have been registered by each in an hour is calculated, and this is compared with the actual amount that would have passed in an hour. The percentage error is then corrected by altering the ratio of the wheels between the snail spindle and the train as already described.

Passing on to the arrangements for performing the above tests, it may be well to remark that the space at the Author's disposal was extremely limited; two rooms, one above the other, each 28 feet long, 12 feet wide at one end tapering away to 3 feet at the

other, having to suffice for testing-room, stores, Frager meter repairing shop and for containing the converters. The upper room was taken for testing, the lower for workshop, converter room and stores; a handlift in one corner formed a convenient means of communication. The testing-room is all that need be described; the narrow end is partitioned off, and a reflecting galvanometer and Wheatstone bridge placed in the chamber so formed; the galvanometer rests on a shelf supported on 'H' iron cantilevers let into the wall, thus avoiding vibration. A space about 6 feet wide on the wall opposite the windows is faced with solid teak thoroughly coated with shellac, and to this are attached all switches; 5 feet 2 inches from the floor a shelf, supported like the one for the reflecting galvanometer, serves as a steady base for the ampere balances. Above this are fixed the primary fuses and switches from which vulcanised india-rubber covered cables, carried in iron pipes chased into the wall, lead to the converters in the room below.

A standard horizontal, tube-pattern, Cardew voltmeter, made by Messrs. Goolden and Co., is fixed below the switches, and shows the pressure on the shunt coils. Beneath the shelf are placed all the secondary switches. With a few trifling exceptions, the secondary connections for large currents are made of bare copper strip 1 inch by $\frac{1}{8}$ inch supported on teak cleats, coated with shellac, the number of strips being proportioned to the current to be conveyed. This is a very convenient and cheap method, and, when neatly done, looks well.

The mercury and Ferranti-Wright meters stand on narrow teak shelves one above the other, fixed on light T-iron cantilevers projecting from the wall.

It seemed desirable to be able to carry on tests of all three kinds of meter simultaneously, and so three separate testing circuits, each with its adjustable resistances and switches, were provided. A fourth circuit was added, for running meters from eighteen to twenty-four hours continuously on full load, to determine whether they would rise to an unsafe temperature.

An obvious way of reducing the cost of testing is to feed the main coils with current at a low pressure, say 10 volts, and to excite the shunts only with 100 volts. After careful consideration, the Author decided not to adopt this plan, partly because he was not absolutely satisfied that it gave results identical with those obtained when both were excited from the same source, and partly because with many meters in series the pressure would have to be raised with large currents, and the additional complication entailed

seemed hardly compensated for by the saving in expense. This objection clearly does not apply to the heating test, in which the shunts are not excited and no measurements are made; and accordingly a converter giving current at 10, 20, or 30 volts pressure at will in its secondary is employed, the lowest pressure that will give the desired current through the circuit being used, this pressure varying with the number of meters in series.

The mercury meter testing circuit is provided with resistances having a conductivity of 1·11 mho, divided into three sets, one of 1 mho, having ten steps of 0·1 mho each; one of 0·1 mho, divided into ten steps of 0·01 mho each; and one of 0·01 mho, divided into five steps of 0·002 mho each. Each set has its members brought to a switch which, by the rotation of a handwheel, joins the desired number of coils in parallel one after the other. In this manner any current up to 111 amperes can be obtained by steps of 0·2 ampere.

It may be well to give a few details respecting these coils and switches.

Coils.—All the wires are of platinoid, and the diameter in no case exceeds $1\frac{1}{2}$ millimetre, the object being to allow them to attain their final temperature rapidly. The coils that have to carry 10 amperes are of No. 17 B. W. G. bare platinoid wire, and are wound in two parallel oppositely directed spirals carried on circular brown porcelain insulators, through which are passed bolts fixed to a light wrought-iron frame. The spirals are steadied by passing over two intermediate sets of insulators. Fig. 13, Plate 11, shows the arrangement. The other two sets of coils are wound on zinc cylinders about $3\frac{1}{2}$ inches in diameter, split parallel to their axes to eliminate eddy currents, and each spiral is wound half in one direction and half in the other.

Switches.—Those for the 100-ampere and the 10-ampere coils have each eleven ring contacts, projecting inwards radially round a semi-circle. The first contact is of sufficient size to carry the whole current of the set of coils to which it belongs, while the other ten are in each case adapted to the current that flows through each member of the set. A brass sector, worked by a handwheel insulated from it, subtending the same angle at the centre of the switch as the eleven contacts, is so placed that when the handwheel is moved continuously in one direction, it is forced successively through all the ring contacts, thus connecting the ten one after the other with the first. The position of the handwheel thus determines the number of coils in parallel, and there is none of the annoyance experienced when a number of separate switches are

used and an effort of memory has to be made to remember which switches allow the desired current to pass; moreover, at full load there is no idle wire. The switch for the 1 ampere set is similar, but, of course, has only six contacts. The three sizes of switch are shown in Figs. 14, 15, and 16, Plate 11. It will be seen that the details vary slightly, but all are provided with brass eyes into which the leads are sweated.

Ferranti-Wright meters are provided with an identical set of resistances and switches.

The Frager meter testing circuit has resistances having a conductivity of 22·2 mhos, the finest adjustment being 0·004 mho instead of 0·002. Only the third set is wound on zinc cylinders, the other two being of bare wire on wrought-iron frames, and the 2-mho set is on two separate frames, having 1 mho conductivity each.

For the circuit for running the meters on full load, the pressure being only 10 volts, coils having a conductivity of 22·2 mhos are used, the adjustment being by steps of 0·04 mho. These coils are, of course, much shorter than those used with 100 volts pressure, but are mounted in the same general way.

With the exception of the last-named circuit, all are fed from an ordinary Ferranti 40-HP. converter, transforming from 2,400 volts to 100 volts, and therefore giving about 300 amperes in its secondary. This current is sufficient, since it is easy to so arrange the runs that it is not exceeded. There is a certain amount of drop of pressure at full load, even in this type of converter, which is exceptionally good in this respect, and the ordinary high-tension service mains being used, the pressure cannot always be relied upon to be exactly 100 volts. In order to obtain a constant pressure, the Author employs a subsidiary regulating converter, having its secondary in series with the main converter; it transforms down from 2,400 volts to $9\frac{1}{2}$ volts, and will yield 300 amperes in its secondary. Connection can be made at ten points of its secondary, so as to obtain the current at a pressure of $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, to $9\frac{1}{2}$ volts. By means of one two-way and one ten-way switch, the pressure can be varied $9\frac{1}{2}$ volts (see Fig. 18, Plate 11). In the primary is a reversing switch, so that this converter can either help or oppose the main. In this way a regulation of $9\frac{1}{2}$ volts either way, or range of 19, is obtained. This, of course, is unnecessarily large, but it was designed for use when the Deptford works were still in a more or less experimental stage and the large margin was very useful.

The current is measured by Lord Kelvin's standard balances,

of which there are three, one reading nominally to 10 amperes but actually to 6 amperes (getting very hot even with this if the current is on for any length of time), one reading to 100 amperes and the third to 600 amperes. All these are required on each testing circuit though only one at a time; in order, therefore, to render any one available for all circuits a switch is employed, consisting of two sets of bars running at right angles to one another, on opposite sides of a slab of slate. At alternate points of crossing, holes are drilled through bars and slate, being tapped in those at the back, and allowing brass bolts provided with insulating handles to pass through the front bars and the slate. These bolts have each a collar which takes a bearing on the front bar when the bolt is screwed into the back, thus connecting the bars. By means of two such bolts any two vertical bars, to which are connected the balances, can be joined to any two horizontal bars to which are brought the circuits. Two spare vertical bars or "bridges" with holes drilled at every point of intersection, take the place of the balance in the circuit without one (usually the heating circuit), and admit of changing from one balance to another without stopping the run. This switch is shown in Fig 17, Plate 11.

The circuit is never broken with the plugs; a single-break "pointsman" switch is placed in each circuit, and admits of runs being started and stopped in any one circuit independently of the others.

The number of meters of any kind required to be tested at once is constantly varying, and if two fixed terminals only are provided between which to join them, a number of different lengths of cable for connecting them thereto are required; these are clumsy and unsightly, and the following has been found to be a convenient device. A series of brass bars, about 2 feet 6 inches long, having bolts and nuts projecting at intervals of 8 or 9 inches, are fixed on teak against the wall above the shelf on which the meters stand; bridging pieces serve to bridge across the gaps when required. Short pieces of very flexible cable, terminating in brass eyes, are used to join the ends of a set of meters to the nearest bolts of separate bars. On removing the bridging-piece connecting the bars, the meters are looped in. Another advantage of this is that a second batch of meters can be got ready at another part of the shelf while the first are running.

Fig. 18, Plate 11, shows diagrammatically the arrangement of the whole testing plant described above.

COMPARISON OF SUPPLY OF ELECTRICAL ENERGY BY METER AND BY CONTRACT.

Having reviewed most of the practical types of meter and the means adopted for testing them, it may be of interest to examine what is the result of supplying consumers by meter instead of at a fixed contract price. The Author has not as much material at his hand as he would wish, but the following examples may throw some light on a subject which is one of great practical importance to supply companies.

In order to have a common basis on which to compare all consumers, irrespective of the number of their lamps, the percentage that the quantity used bears to the maximum quantity that could be used if each lamp burnt for twenty-four hours per day, has been taken; for each consumer a curve has been plotted, having this percentage as ordinates, and weeks as abscissae. A whole year is given in each case, but unfortunately it is not possible to give the same year for each. Now when lamps are paid for by contract, it is assumed that each 33-watt lamp is alight for three hours each day throughout the year; taking the percentage that this quantity bears to the maximum possible, i.e., $12\frac{1}{2}$ per cent., and setting this up as ordinate for each week in the year, a rectangle is formed. In order to find whether it is profitable to supply by meter, it is only necessary to compare the area of the curve with that of the rectangle; if this is greater than unity it is profitable, if less, the contract method is preferable.

The following are the cases selected:—

Theatre.—An inspection of Fig. 19, Plate 12, shows that, with few exceptions, this keeps well above the contract line, and the ratio of the areas is 1·4, thus showing a large gain from supply by meter.

Restaurant.—Here again (see Fig. 20, Plate 12) the consumption is heavy throughout the year, and the meter brings a large return, the ratio of the areas being 1·3.

Club.—The only club available for this comparison is a rather unfortunate example; it is shown in Fig. 21, Plate 12, and it comes out 0·98, which is much below what the Author believes from experience to be the average of this class of consumer. In support of this, a portion of a curve for another club is given in Fig. 22, Plate 12, where the consumption is much heavier; the ratio cannot here be given as there is not a complete year, but the curve is up to the contract line even in the summer months, and it is clear it must be much heavier in the winter.

Shop.—Two examples differing widely are given :—

(i.) West End jeweller, Fig. 23, Plate 12. The demand is kept up well throughout the year, the ratio being 1·02.

(ii.) West End china merchant, Fig. 24, Plate 12. Here is an example of the gross injustice of the contract system to some consumers. The consumption during the months from June to September is practically nil, and the ratio of the areas shows that in this case only one third (ratio = 0·3) of the amount charged for by contract is used.

Library.—This (see Fig. 25, Plate 12) is very similar to the last case, the ratio being 0·5.

In order to obtain any safe deductions as to the relative value of different consumers, the mean of many curves for each class must be taken, but the above examples serve as an indication. The consumption of a theatre, for instance, is seen to be uniformly high, with occasional extra loads owing probably to morning performances or extra rehearsals. Restaurants being open late, always take a large proportion of their full load, while shops vary much according to their character, those closing early consuming practically nothing during the summer months and being therefore unproductive.

The curves just given afford conclusive evidence on one point at least, namely, that the only equitable method of supply is by means of meters, and the Author trusts that he has made it clear that if there is not yet a perfect meter, there are nevertheless within the reach of companies employing either alternating or continuous currents, several instruments sufficiently reliable under working conditions, which have stood the test of time and practical work.

The Paper is accompanied by three sheets of tracings from which Plates 11 and 12 have been prepared.

OBITUARY.

GEORGE BIDDELL AIRY was born on the 27th of July, 1801, and died on the 2nd of January, 1892. His father was a Lincolnshire man, and his mother a member of the well-known family of Biddell of Suffolk, but he was born at Alnwick in Northumberland, where his father (who was connected with the Inland Revenue Department) happened to be stationed at the time. He was educated chiefly at the Colchester Grammar School, and a great part of his time was spent with his uncle at Playford, near Ipswich. At this village Thomas Clarkson, "the friend of slaves," resided. He was much struck by the ability and practical mind of the boy; and it was mainly due to his earnest advice that young Airy was entered at Trinity College, Cambridge. His college career was very brilliant, and he came out as Senior Wrangler in 1823. He was elected Lucasian Professor in 1826, and delivered an annual course of lectures on Experimental Physics which made a great impression on all who attended them. In 1828 he was elected Plumian Professor of Astronomy, in virtue of which he became Director of the Cambridge Observatory. He had already written various important treatises on Gravitational Astronomy, such as "The Lunar and Planetary Theories," "The Figure of the Earth," &c.; he now turned his attention to the practical working of an observatory, and introduced improvements of the highest value in the reduction and publication of observations. In 1830 he married a daughter of the Rev. Richard Smith of Edensor, Derbyshire.

Mr. Airy was appointed Astronomer Royal in 1835, which post he held until 1881. Under his energetic management every department of the Observatory at Greenwich was wholly re-organized. The methods which had been found so efficient at Cambridge were adopted, and the observations were reduced and published with unvarying punctuality. He designed and introduced new instruments far superior to the old ones in power and in mechanical construction. A magnetic observatory was established, and magnetical and meteorological observations were recorded daily. A vast work of great importance to astronomy, viz., the reduction of the Greenwich observations of the moon and planets, which had accumulated since 1750, and which in their

unreduced condition were totally useless to astronomers, was undertaken and completed after many years' labour. In addition to his regular routine work, he observed the total eclipses of 1842, 1851 and 1860, and organized the British expeditions for the observations of the Transit of Venus in 1874. In 1854 he determined the mean density of the earth by pendulum experiments in the Harton coal pit, thus at last accomplishing the object which he had attempted in a mine in Cornwall in 1828, but had failed to carry out by reason of an accident in the working of the pit.

Throughout his long tenure of office Mr. Airy was regarded by the Government as its chief scientific adviser, and was frequently consulted. He was one of the members of the Railway Gauge Commission. He was Chairman of the Commission for re-establishing the Standards of Length and Weight, after the destruction of the old standards by fire, and on various occasions rendered much service to the Standards Department of the Board of Trade. He investigated very exhaustively the cause of the disturbance of the compass in iron ships, and applied efficient remedies. He instructed the officers charged with the duty of setting out the boundary between Canada and the United States, so far as the astronomical observations were concerned. He reported on the cause of the alleged inefficiency of the light in English lighthouses, and on many other matters. He was extremely well versed in optics and mechanics, both theoretically and practically, and this knowledge stood him in good stead in the design of the new instruments required for the Observatory, and of the buildings to contain them. He took great interest in all important engineering works, and from his remarkable knowledge of the principles and theory of construction, and of the strains in ironwork, he was often consulted by Stephenson, Brunel, and other engineers, as to the great works upon which they were engaged.

Mr. Airy was elected an Honorary Member of the Institution on the 28th of June, 1842. He occasionally attended the meetings between the years 1852 and 1877, and spoke on the Papers under discussion. In April, 1858, he addressed to the Institution a Communication entitled "Further Observations, Explanatory of former Remarks, on the Submerging of Telegraph Cables."¹ Again in 1867 he contributed a Paper "On the Use of the Suspension Bridge with Stiffened Roadway, for Railway and

¹ Minutes of Proceedings Inst. C.E., vol. xvii. pp. 298 *et seq.*

other Bridges of great Span,"¹ for which he was awarded a Telford medal. And in 1881 he presented an elaborate set of tables of "Logarithms of the Values of all Vulgar Fractions, with Numerator and Denominator not exceeding 100, arranged in order of Magnitude."² His treatises and writings were very numerous, for any subject which had a distinctly practical object, and could be advanced by mathematical investigation, possessed interest for him. His chief separate publications were the "Mathematical Tracts," chiefly on the lunar and planetary theories and on the undulatory theory of light; the treatise entitled "Gravitation;" an article on tides; the Ipswich lectures on Astronomy; and treatises on Sound, Magnetism, and Errors of Observation. But he contributed many valuable Papers to the Transactions of the Royal Society; the one, perhaps, which attracted most attention amongst astronomers being that on "The Inequality of long Period in the Motions of the Earth and Venus." His connection with the Royal Astronomical Society was very close, nearly all his Papers on purely astronomical matters being communicated to that society. He occasionally contributed articles on miscellaneous subjects to various newspapers and journals. Most of these, and amongst them "The Landing of Julius Cæsar in Britain," were published in the *Athenæum*.

Mr. Airy was a Fellow of the Royal Society (of which he was President from 1871 to 1873), a Fellow of the Royal Astronomical Society (of which he was several times President), and a member of various other learned societies; he was also a Corresponding Member of the Institute of France. He received numerous medals and marks of distinction in recognition of his services to astronomy and science, and was made a Knight Commander of the Order of the Bath in 1872. But of all the honours he received, there was none he valued so much as the Freedom of the City of London, which was presented to him in 1875; the special grounds of this honour were the practical nature of the work he had done, and in particular his valuable investigation and correction of the errors of the compass in iron ships.

The chief features of his character were independence of thought and self-reliance, an extremely practical turn of mind, and a remarkable love of order. His practical nature showed itself in everything he did. His mathematics were always directed to some useful and practical end, for he had a positive aversion to mathematical investigations of a purely speculative

¹ Minutes of Proceedings Inst. C.E., vol. xxvi. p. 258.

² *Ibid.*, vol. lxx. p. 271.

nature. In carrying out an investigation he always kept his object clearly in view, and made for it in the most direct manner, wholly regardless of what may be termed the elegancies of mathematics. Long arithmetical calculations had no terror for him, so skilful was he in expedients for facilitating them. At the same time he was a keen economiser of labour, and was careful to avoid carrying calculation to a greater degree of accuracy than was necessary for the immediate purpose. His love of order was most singular, and might almost be regarded as the ruling feature of his mind. He looked upon mathematics as the handmaid of order; and in the routine work of the Observatory, whether in general regulations, in the arrangement of documents, or in the reduction of observations, order was carried to its extreme limits. Mr. Airy had a very strong constitution, and his regular habits, both of work and exercise, kept him in good health. His custom was to work in his official room from about nine to two, and to dine about half-past three; he then worked in the evening, in the same room with his family, from about seven to ten, where his powers of abstraction were remarkable. He was very fond both of the classics and of general literature, and took special interest in antiquarian investigations. His memory was very tenacious, and was stored with abundance of English poetry, which he often referred to as an ever-present relief and comfort to his mind. He was a man of great simplicity of character, combined with strong common sense, and was nowhere so happy as in the little country village where he had spent much of his youth and with which he kept up a close connection throughout his life.

H.M. DOM PEDRO II DE ALCANTARA, ex-Emperor of Brazil, was born on the 2nd of December, 1825. At the age of five he succeeded to the throne of Brazil on the abdication of his father Dom Pedro I, Bonifacio José de Andrade e Silva being appointed regent. In 1833 a Council of Regency was appointed. During the next few years so many intrigues took place that in 1840 the Chambers declared that the Emperor, although only in his sixteenth year, had attained his majority. On the 13th of July in that year he assumed the reins of government, his coronation taking place on the 18th of July in the following year. On the

4th of September, 1843, the Emperor married Donna Theresa Christina Maria, daughter of the late Francis I, King of Sicily, by whom he had two sons and two daughters; both sons died in childhood, and of his daughters, the eldest only, the Condessa d'Eu, survives him. An entirely bloodless revolution, on the 15th of November, 1889, deprived him of his crown and changed the empire into a republic. His Majesty then lived quietly in Europe, mainly occupying himself in those philosophical avocations to which he had been addicted all his life, and which had caused his name to be respected by men of science of all nations.

Politically the great work of his life, and that which, by the irony of fate, became ultimately the cause of his deposition, was the freeing of the slaves in Brazil. An amiable and benevolent man, Dom Pedro appears from the first to have felt the reproach to his country involved in the existence of slavery; but the difficulties in the way of dealing with an established institution in a country where the national prosperity seemed to depend upon its continuance were so great that it soon became evident that the proposed reform must be gradual. The first step was taken in September, 1871, when it was enacted that every child subsequently born of slave parents should be free, and all the slaves belonging to the State and to the imperial household were declared free from the same period. Provision was also made for an emancipation fund to be annually applied to the ransom of a certain number of slaves owned by private individuals. It was anticipated that by this means slavery would cease to exist in a few years; the expectation, however, was not fulfilled, and in 1884 the Ministry, at the wish of the Emperor, introduced a Bill to bring about the total abolition of slavery within ten or twelve years. This being defeated led to a change of Government, but eventually a modified measure was passed by a coalition of the two parties in the State. Finally in the Session of 1888 the question was set at rest by the Chambers voting the immediate and unconditional abolition of slavery.

This measure was extremely distasteful to the planters, and there is no doubt that the importance of the agitation set on foot by them against it was fully realized by the astute leaders of the Republican party, whose schemes were thus greatly favoured by a conjunction of events of which they took full advantage. It has been said that, had Dom Pedro firmly resisted the proceedings of the leaders of the military revolt on the 15th of November, 1889, he could easily have frustrated their designs, but rather than involve his country in bloodshed he preferred to acquiesce in the

demands of this military dictation which had assumed power, and to pass the remainder of his days in exile.

The high culture of Dom Pedro, and the simplicity of his tastes, caused him everywhere to be regarded with the utmost respect. One of the studies he was most devoted to was astronomy, and it was mainly by his means that the national Observatory at Rio de Janeiro was raised to a footing of equality with similar establishments in Europe. He was an ardent votary of education, and of those branches of knowledge which are known in England as social science, but he appears to have thought with Pope that "the noblest study of mankind is man." His greatest enjoyment seems to have been in foreign travel, when, for the time free of the cares of state, he could assume the *rôle* of a private gentleman, and, mixing with all classes of society, contemplate life with the interest of a keen student of human nature. The days of his exile were thus congenially passed until his death in Paris on the 4th of December, 1891.

It was during his first visit to Europe that his Majesty was elected an Honorary Member of the Institution, his diploma bearing date the 9th of January, 1872. He had always taken a great interest in the material development of his country, and had become acquainted with the Society through the large number of English engineers belonging to it who had found employment in the public works of Brazil. The Emperor took the most intelligent interest in all engineering works, paying frequent visits to those from time to time in progress in Rio, amongst others, the Imperial Dock, the drainage works, and the Dom Pedro Segundo Railway. In 1859, when the Emperor visited Pernambuco, he devoted a good deal of time to the various schemes which had been proposed for the improvement of that port. On the 21st of September, 1861, he inaugurated the Imperial Dock in Rio, having exploded by electricity the first series of mines in connection with that work on the 5th of November, 1857. And on the 30th of May, 1871, on his way to Europe, he landed at Pernambuco and inaugurated the drainage works in that city. He was in the habit of asking numerous questions and of making copious notes on the occasion of visiting these works. It was therefore felt that so fitting an opportunity as his visit to Europe afforded of testifying to the respect in which his Majesty was held by the profession in this country should not be allowed to pass. He had made a long visit to London in the summer of 1871, during which he had renewed his acquaintance with Mr. Charles Vignoles, the then President. This gentleman accordingly superintended the formalities

attendant upon the Emperor's election, and subsequently took part in a deputation which proceeded to Paris to present his diploma and obtain his Majesty's signature to the register of the Institution.

The connection thus inaugurated was destined to prove more than an ornamental one, for it led to the election of many Brazilian engineers into the Institution, and, ultimately, to this body being recognized by the Brazilian Government as a professional organization, the diploma of which was equivalent to the national degree of Doctor of Engineering in the case of candidates for employment as State Engineers.

HIS ROYAL HIGHNESS PRINCE ALBERT VICTOR CHRISTIAN EDWARD, K.G., K.P., K.T., Duke of Clarence and Avondale and Earl of Athlone, was the eldest son of H.R.H. the Prince of Wales, and was born at Frogmore on the 8th of January, 1864. He received his earlier education from a staff of tutors specially selected to supervise his training. At the age of thirteen he was entered as a naval cadet on board the training-ship "Britannia," where he spent two years under the care of Captain Fairfax. In 1879 the Prince went as a cadet on H.M.S. "Bacchante" to the West Indies, and in September of the following year he, and his brother Prince George of Wales, made a longer voyage as midshipmen on the same vessel, under the command of Captain Lord Charles Scott, with Canon Dalton as tutor and Mr. J. W. Lawless as naval instructor. In the course of a long and interesting cruise the Princes sailed round the world, and visited many of its most remarkable countries and scenes. Under the direction of their tutor they kept an elaborate diary of the voyage, which was subsequently published; but, although the trip was to a large extent one of instruction and pleasure, they were granted no special exemption from the ordinary duties of their naval rank while on active service. They returned in the summer of 1882.

After a year's private study the Prince was entered in October, 1883, as an undergraduate at Trinity College, Cambridge, and about the same time was created a Knight of the Garter. He remained at Cambridge for two years, spending part of the vacations at Heidelberg, with the object of improving his knowledge of German. As it was not intended that he should go

through the complete academic course at Cambridge, he did not devote himself specially either to the classical or scientific studies of the University, but received instruction from private tutors, and gave considerable attention to modern literature, history, and constitutional law. On leaving Cambridge his Royal Highness spent some months in preliminary study at Aldershot, and was then gazetted to the Royal Artillery. His actual military duties, however, commenced with his transfer to the 10th Hussars; for three years he resided mainly at York, the headquarters of that regiment, in which he was first a subaltern and then a major.

On the 31st of January, 1885, the Prince made his first public appearance in England by opening the Whittington Home for Boys at Whitechapel. On his twenty-first birthday he was elected a Bencher of the Middle Temple, and in the following June the Freedom of the City of London was conferred upon him. He opened, in February, 1886, a new wing of the Cambridge Union Society's buildings, and, in May of the same year, the International Exhibition at Edinburgh. In the following year he made a tour in Ireland with Prince George, and in 1889 visited India and Burma.

On his return to England the Prince was created a peer, with the title of Duke of Clarence and Avondale and Earl of Athlone, and, in June, 1890, took his seat in the House of Lords. About this time his health, which had never been robust, gave some cause for anxiety, but no danger was apprehended, nor was it doubted that the Prince was in his normal condition when, in December, 1891, the engagement of His Royal Highness to his cousin the Princess Victoria Mary, daughter of the Duke and Duchess of Teck, was announced. The preparations for the wedding were in active progress when the Prince was attacked by influenza. Pneumonia supervened, and the course of the disease was so rapid that it terminated fatally on the 14th of January, 1892, only three days after the first intimation of the illness reached the country.

The Duke of Clarence and Avondale was an active Freemason. Initiated in 1885, he was appointed two years later Senior Grand Warden, and in 1890 was installed by the Prince of Wales as Grand Master of Berkshire. His Royal Highness was present at the annual dinner of the Institution, held in Lincoln's Inn Hall on the 27th of March, 1886, and was elected an Honorary Member on the 5th of February, 1889.

RICHARD BOXALL GRANTHAM was the eldest son of the late John Grantham, Civil Engineer, and was born in Church Street, Croydon, on the 13th of December, 1805. He was sent to school at Edenbridge, Kent, and on leaving, at the age of about sixteen, commenced his professional education in the drawing-office of the late Augustus Pugin, the architect. Among his fellow pupils were the late Charles Mathews the younger, Mr. (afterwards Sir) James Pennethorne, and Mr. Benjamin Ferrey, who all subsequently attained distinguished positions. While there, he measured and prepared the drawing of the colosseum or diorama in the Regent's Park which appeared in Pugin and Britton's "Illustrations of the Public Buildings of London." It may be noted that the office hours were at that time from 6 A.M. to 6 P.M.

In the year 1823 Mr. Grantham went to Ireland to assist his father, who had been occupied since 1819, under the late Mr. John Rennie, in making a survey of the Shannon for Government, for the purpose of reporting on works for the prevention of floods in the valleys of that river and its tributaries. This report was printed in the form of a memorial to the Lords of the Treasury. Soon afterwards he was engaged with his father in rebuilding the bridges over the Shannon at Limerick, Killaloe, and Portumna, with arches of increased span so as to give more waterway for floods. He also assisted his father in introducing steam-navigation on that river from Killaloe to Shannon Harbour. Later on he and his brother, the late Mr. John Grantham, were employed with their father by Messrs. John and George Rennie in surveying a line of railway from London to Birmingham now forming part of the Great Western system. In 1834, the year after his father's death at Killaloe, he was appointed to the county surveyorships of King's County and Clare, and, in 1836, to the surveyorship of the county of Limerick.

At the end of 1836, Mr. Grantham returned to England and was engaged by the late Mr. I. K. Brunel as an assistant on the construction of the Great Western Railway, superintending in particular the Brent Viaduct, and afterwards as resident engineer carrying out the branch line from Gloucester to Cheltenham, known at that time as the Cheltenham and Great Western Union. Leaving the service of the Company in 1844, he came to London and established an office in Robert Street, Adelphi. For the next two years he was employed, principally by Sir John Rennie, in making surveys for railways, among which the principal were

the London and Manchester Direct, the Direct Northern, the Direct Norwich, the Birmingham and Gloucester, the Derbyshire, Worcester and Staffordshire, the Chester and Manchester, the Newry and Enniskillen, and a portion of a line from London to York.

The railway mania having abated, Mr. Grantham turned his attention to sanitary matters, and in 1847 went to Paris to examine the Abattoirs, a description of which he furnished to the Institution¹ in the hope of establishing a similar system in London. He prepared designs for a cattle-market and slaughter-houses at Islington, a company being formed for the purpose of erecting them, and, although its objects were not realised, the present market and slaughter-houses were constructed on very similar lines. He was then busily employed on a variety of works; in 1852 he surveyed a portion of what is now the direct Portsmouth line of the London and South-Western Railway under the late Mr. Errington; from 1854 to 1857 he assisted Mr. John Clutton in the disafforesting and drainage of Hainault Forest, Essex, now a valuable agricultural property; and in 1858 he surveyed a line from London to Bury St. Edmunds for Messrs. M'Clean and Stileman. In 1856 and following years he was engaged in constructing the Forest of Dean Central Railway which he had previously surveyed, and which is now worked as a branch of the Great Western Railway, and he afterwards made several surveys in and near Monmouth and the Forest of Dean.

His experience on the Shannon, and in carrying out the drainage of Hainault Forest and other similar works, led Mr. Grantham to recognise the want of improvement in legislation on the subject of arterial drainage in this country. He therefore associated himself with Mr. John Clutton and Mr. J. Bailey Denton in drawing public attention to the matter, and attended a meeting at the Hanover Square Rooms in December, 1860. This led ultimately to the passing of the Land Drainage Act, 1861, under which he was appointed inspector, subject to the instructions of the Inclosure Commissioners. For the following three years he was engaged with Mr. Clutton in carrying out the marling of about 1,500 acres of Crown property in Delamere Forest, Cheshire. He presented a detailed description of this work and of the geological features of the county to the Royal Agricultural Society,² at which he subsequently took part in the discussion upon a Paper on the "Re-

¹ Minutes of Proceedings Inst. C.E., vol. viii. p. 66.

² Journal of the Royal Agricultural Society, vol. xxv. p. 369.

clamation of Land from the Sea.”¹ From 1861 to 1883 he held as Drainage Inspector, forty local inquiries, resulting in the formation of as many drainage districts. Amongst those inquiries was one in 1871 for the purpose of forming a large drainage area in the upper valley of the Thames above Oxford, the outcome of which was the passing of the Thames Valley Drainage Act, constituting a drainage board for dealing with improvements in the main river and having under its control six district boards entrusted with powers for improving and maintaining the tributaries. The total watershed of this district was 826,900 acres and the taxable area 55,472 acres. He contributed to the Proceedings of the Institution a valuable Paper dealing with the whole question.² In the winter of 1872-73 Mr. Grantham was sent by the Inclosure Commissioners to inquire into and report upon the floods in the valleys of the rivers in Somersetshire, 69,000 acres of which were then inundated. A large part of this area was again under flood during last autumn. The report³ was printed and laid before the House of Commons. An Act called the Somersetshire Drainage Act was passed in 1876, constituting a drainage district upon similar lines to the Thames Valley Drainage Act, with a watershed of 607,360 acres and a taxable area of 121,437 acres.

For some years he had interested himself in the sewage question, and had been associated with Mr. J. Bailey Denton in prosecuting inquiries on the subject. In 1869 he attended the meeting of the British Association at Norwich, and was the means of obtaining the appointment of a committee, of which he was nominated chairman, to inquire into the treatment and utilization of sewage. After reporting for several years the Committee concluded in favour of the disposal of sewage on land, where practicable, as the best means of purifying it. He subsequently carried out many sewerage and sewage-disposal works, and for several years was engaged with Messrs. Clutton in executing drainage and other works on the estates of the Ecclesiastical Commissioners and of the Commissioners of Woods and Forests. It may also be mentioned that in 1860 he was appointed, in conjunction with his brother, Mr. John Grantham, engineer to the Northern Railway of Buenos Ayres, and that for some years he acted as engineer to the Quebrada Railway Company in Venezuela, a

¹ Journal of the Royal Agricultural Society, 2nd Series, vol. iii. p. 659.

² Minutes of Proceedings Inst. C.E., vol. xix. p. 122.

³ “Report on the Floods in Somersetshire in 1872-73.” Richard B. Grantham. Stanford, London, 1873.

portion of that line being carried out under his direction and superintendence; it was intended to connect some copper mines with the coast, and had been personally surveyed many years previously by the late Sir John Hawkshaw.

But perhaps the most recent and noteworthy work by which Mr. Grantham's name will be remembered is the reclamation of Brading Harbour in the Isle of Wight, which he carried out to completion in 1879-80. The harbour, comprising some 700 acres, was reclaimed about the year 1620 by Sir Hugh Myddelton, but the sea subsequently destroyed the embankment. The present embankment is 35 feet wide, and forms the high road from St. Helen's to Bembridge. New timber wharves and sluices for the discharge of the River Yar were built, and the railway from Brading to Bembridge was carried out, under his direction.

From the first meeting of the British Association at York in 1831, Mr Grantham was a frequent attendant at its annual gatherings, the last occasion on which he was present being at the Bath meeting in 1888. He was elected a Fellow of the Geological Society in 1833, and continued the connection up to the date of his death. He was associated with the founders of the Surveyors Institution, and promoted its interests by serving on the Council from 1872 to 1883, and by contributing several Papers.

From the time he entered Mr. Pugin's office until 1891, about seventy years in all, Mr. Grantham's life was one of continuous hard work, and to the end the desire to be at work was strong within him. As a husband and father he was the kindest and most generous of men. Conscientious and ardent in his work and of a sanguine temperament, difficulties never caused him to despond or ruffled his prevailing good temper. Genial, bright and courteous in manner, he was fond of society, particularly that of men of science, and it was a pleasure to him to attend the meetings of the Smeatonian Society of Civil Engineers and of the Geological Club, which until a year ago he did frequently. He was elected and acted as President of the former society in 1890. He attended at his office as lately as Friday, the 27th of November, but the effort overtaxed his strength, for on the following Sunday he lost all power of moving and gradually sank, passing peacefully away on the 5th of December, 1891.

Mr. Grantham was elected a Member of the Institution on the 25th of June, 1844, and was at the time of his death one of its oldest members. In former years he frequently attended its meetings, and, in addition to the Papers referred to, for both of

which he received Telford premiums, he presented a clinometer which was placed in the library of the Institution.

HENRY TEMPLE HUMPHREYS was born on the 20th of December, 1839, in Oxford Street, London, and was the youngest child of Griffith Humphreys and his wife, Sarah Leggett, a daughter of Henry Temple, of Sandwich, Kent. He was for a short time at the City of London School, but when his family moved to Bayswater he received the rest of his education at private schools nearer home. As he evinced a decided predilection for engineering, he was placed for six months under tutors for mathematics and technical drawing, after which, in August, 1854, he was apprenticed for five years to Messrs. John Rennie & Co. of Blackfriars. It was intended that he should acquire the practical part of the profession with this firm by passing through their shops, keeping to workmen's hours; but a delicate frame, together with the long distance to be traversed night and morning, soon showed this to be impossible, and the Messrs. Rennie kindly transferred him to their drawing-office, where attendance was not required until nine o'clock. On the termination of his apprenticeship in 1859 he was retained as an Assistant. In February, 1861, he went to the Canal Iron Works, Limehouse, as Chief Draughtsman, which post he resigned in the following December in order to accompany Mr. John Bourne to Karachi for the purpose of making preliminary surveys for the Oriental Canal and Irrigation Company.

Returning to England in August, 1862, he was engaged as an Assistant Engineer on the Thames Valley Railway during part of 1863. On the 9th of December of that year he left to take up an appointment as Chief District Engineer under Mr. Alfred Rumball on the Buenos Ayres Great Southern Railway, which line he helped to lay out. In the following September he was again in England, and spent the remainder of the year and the following spring in fulfilling temporary engagements on the South Wales Railway at Cardiff and on the North Eastern Railway at Newcastle-on-Tyne. Late in 1865, after being in the office of Mr. Hawksley in Westminster, he was appointed by that gentleman Resident Engineer on the extension of the works for the water-supply of Whitehaven. He was occupied on those works until January, 1866, when a severe attack of rheumatic fever

compelled him to resign. On recovering, he was engaged in the Borough Engineer's office at Portsmouth, and subsequently in the office of Mr. Thomas Winans of Clarges Street, London.

Early in 1868, Mr. Humphreys obtained a Government appointment as Executive Engineer in the Indian Public Works Department. He arrived at Calcutta on the 21st of March, and was stationed at Bangalore in charge of irrigation works. Finding, however, that his health suffered from the climate he returned to England in May, 1869. In October of the same year he obtained in open competition at Dublin the County Surveyorship of West Limerick. In the following January he entered upon the duties of that post, which he retained until his transfer in 1875 to the County Surveyorship of Galway. His health becoming much shattered by exposure to the cold damp air, and by the fatigue undergone in traversing the long distances of his extensive district, Mr. Humphreys resigned this appointment in January, 1878, after which his engineering career was practically at an end. That his mind was still active was shown by the fact that he continued to produce inventions. These had begun when he was only in his nineteenth year with one relating to projectiles, and embraced, amongst others, a cycloscope for surveying purposes; the *Clamor Oestis*, a self-regulating sea-screech to warn ships during fogs; and an elevated post and rail-way for ready and cheap construction in new countries without disturbance of land. A description of the latter may be found in the library of the Institution. In 1861 he published a pamphlet on the Unsoundness of Indian Guarantees. He also wrote, in 1881, a notice of Mr. Latimer Clark for "Celebrities of the Day," and, subsequently, an article on "Competitive Examinations" for *The Nineteenth Century*.

On resigning his Irish post, Mr. Humphreys spent some two years in London, and then passed the rest of his life in various parts of Scotland. He did not marry. His death took place from laryngeal phthisis on the 27th October, 1891, at Clady House, Cairnryan, near Stranraer. He was a man of much intellectual power, of active habits, and of great force of character; and his genial disposition and musical ability made him very popular in society. He always took great interest in economic and social problems. Mr. Humphreys was elected an Associate of the Institution on the 7th of February, 1865, and was transferred to the class of Member on the 8th of March, 1870.

WILLIAM MILLS was born at Harrow on the 16th of December, 1818, and was educated at Harrow School under Dr. Longley, his father, the Rev. Dr. Mills, being an assistant master there at the time. It was intended that he should go to Canada to join some old friends of the family, but before doing so his father, then head master of Exeter School, sent him for a year into Kent to learn farming. His stay in Canada was short but exciting. During the rebellion he became one of Sir Francis Head's Volunteers, being trained for months by an old Indian officer, Colonel Johnson. With some half dozen others he effected the capture of Sount, the leader of the attack on Toronto. One morning they saw two men in a small boat, frozen in, on the waters of Lake Erie. After great labour and frequent immersions, Mills and his friends managed to push a boat over and through the broken ice, and rescued them from their perilous position. Suspicion being aroused by the conduct of the men, they were taken before a magistrate, when one of them was found to be the rebel leader Sount, for whose capture a reward had been offered by the Government.

Soon afterwards Mr. Mills returned to England, and in August 1838 became a pupil of Mr. Hemming, the contractor for the Bristol and Bridgwater section of the Bristol and Exeter Railway, then being constructed under Messrs. Brunel and Gravatt. On the expiration of his pupilage in 1842 he went to Lough Foyle where he was engaged on drainage works under Messrs. Gravatt and Hemming. He then received an offer of employment on the Cambrian and South Shropshire Railway under Mr. Gravatt, which he accepted, as he desired to remain with that gentleman, at whose hands he had experienced great kindness and consideration. Subsequently he carried out some engineering work in Norfolk and also in Ireland, but in neither place did he remain long.

In the year 1849 Mr. Mills became connected with the surveys of the East Kent Railway, for which he prepared the plans and assisted in obtaining from Parliament in 1853 the Act of Incorporation. He was then appointed Resident Engineer on the section between Chatham and Dover, Mr. Joseph Cubitt being Consulting Engineer, and had responsible charge of the works on that line and its extensions, now known as the London, Chatham and Dover Railway. On the death of Mr. Cubitt in 1872 he became Chief Engineer, a post which he retained for the remainder of his life. He designed and carried out the works of the Holborn Viaduct Station, the Blackfriars Goods Warehouse and

Widening, and many other important extensions; but of all the undertakings upon which he was engaged for the Company, Mr. Mills often spoke of the bridge over the Medway at Rochester as the most arduous, and it is supposed that his health suffered to some extent permanently from his having to spend part of each day for several months under high atmospheric pressure, in the cylinders on which the bridge was built. He became slightly deaf at that time, an infirmity which increased with advancing years.

For some time his friends had seen that he was failing; in October 1891, he took to his room, almost to his bed, and died on the 8th of December following, in the seventy-third year of his age. Mr. Mills was elected a Member of the Institution on the 1st of March, 1870.

WILSON WEATHERLEY PHIPSON was the third son of the late Samuel Ryland Phipson, of Ladywood, near Birmingham, where he was born on the 31st of August, 1838. Both his father and mother devoted themselves to the welfare of their children; the former, who had been educated at the University of Jena, kept open house at Ladywood, and amongst the visitors with whom young Wilson was thus brought in contact, were Sir Henry Bulwer, Thomas Carlyle, Macready, Dr. Kennedy (of Cambridge University), and other distinguished men.

About the year 1847 his father lost a large sum of money by the failure of the North of England Joint Stock Bank and of a bank in the United States in which he had become largely interested. These losses induced him to leave England for some continental city where living and education were cheaper. Wilson was between ten and eleven years of age when his parents migrated to Brussels. He was educated there, and also at Paris, where his family resided for a few years before they returned to England, and where, through the instrumentality of Earl Cowley, his father was enabled to enter him as a student at the École des Ponts et Chaussées. This was about 1857. Whilst in Brussels he was for a short time a pupil of Dr. Van Hecke, who had discovered a new method for the heating and ventilation of hospitals which had already given some very satisfactory results both as to economy and efficiency. When his studies at the French School of Engineering were completed he assisted Van Hecke to warm and ventilate the hospitals Necker and Beaujon in

Paris, and subsequently in carrying out similar work at Bordeaux and in some of the Government buildings of Holland.

At this time Wilson Phipson was living with his parents in Brussels. His musical talents and genial qualities rendered him a general favourite. He made the acquaintance of the late Prince George of Prussia, who endeavoured to induce him to become his secretary and travelling companion. Phipson had, however, too many ties in Belgium, and he did not speak German. Though barely eighteen years of age, he had many excellent friends, some considerably older than himself, among whom were Baron von Rosenberg of Dresden, Leloup, Engineer-in-chief of the Northern Railway of Belgium, and Victor Eeckhout, the well-known Belgian painter. In the year 1859 his family came to London, whither he accompanied them with the object of introducing a new system of heating and ventilation devised by his old master, Van Hecke. The amount of prejudice and ignorance he had to overcome, both in the medical world and amongst architects, was astonishing. The art of ventilation was entirely in its infancy, and although complaints about the impure atmosphere of the law courts, theatres, hospitals, and other public buildings were of daily occurrence, he could not induce anybody to take the matter up. He published a pamphlet setting forth the great benefits of the new system, and read a Paper before the Medical Officers of Health who met at the Marylebone Court House. Several physicians who attended the meeting admitted the economy and efficiency of his scheme, but beyond this no immediate result was apparent. At length, however, through the influence of his father, he obtained the contract to warm and ventilate Baron Rothschild's private residence in Piccadilly and the bank in St. Swithin's Lane. The success of these works attracted the attention of some of the leading architects of that day, and several other important buildings were placed in his hands. In succeeding years many large banks, insurance offices, and other extensive buildings followed, among which may be mentioned the Royal Albert Hall, the Natural History Museum at Kensington, Exeter Hall, the Alexandra Palace, the National Provincial Bank, the Criterion Theatre, the University Medical Schools at Edinburgh, the Royal Exchange and Law Courts at Birmingham, the Royal Infirmary, Liverpool, and the new University buildings at Glasgow, a description of which he presented to the Institution.¹

¹ Minutes of Proceedings Inst. C.E., vol. lv. p. 124.

In 1867 he married Elizabeth Humberstone Newcome, daughter of a solicitor. A short time previously his brother, Dr. Phipson, had settled in London. The two brothers were always staunch friends, and used to meet frequently at their father's house at Putney. In spite of increasing professional work, Mr. Phipson was for several years an active member of the Surrey Rifle Volunteers. In 1880, he again went to Paris, to ascertain whether any improvements had been made in the heating and ventilation of public buildings since his time. As the extent and importance of his work increased, his career became one of great anxiety and constant toil. Under his hands the heating and ventilation of large buildings had been greatly improved. He had long since abandoned the old plan and had adopted low-pressure steam on the gravity, or open circulation system, by which not only is the exact temperature required kept up, summer and winter alike, in any given section of the building, but if by accident the thermometer in any particular room shows an abnormal degree, it is at once indicated by an electric current which affects the dial fixed in the engine-room, where the man in charge can see at a glance what has happened and can rectify it without delay. Near the boilers are a series of these dials, corresponding to the different sections of the building.

In 1866, Mr. Phipson proposed to remedy the ventilation of the Birmingham Town Hall. He was scarcely listened to. In 1891, a quarter of a century later, he was invited to undertake the work, just before the triennial musical festival. It was his last work. The fatigue of long railway journeys—for weeks together he would sleep in a Pullman car—added to domestic affliction and trouble, must latterly have told upon his usually robust health. During the month of October of this year he travelled over three thousand miles in little more than a fortnight, to superintend works recently completed and to attend consultations. It was more than even his strong constitution could stand; he died very suddenly from the rupture of a blood vessel on the morning of the 21st of October, 1891, at the age of fifty-three.

Mr. Phipson was elected an Associate of the Institution on the 12th of January, 1869, and was transferred to the class of Member on the 26th of February, 1878.

GEORGE SIBLEY, born on the 12th of August, 1824, was the son of the late Robert Sibley, who was one of the earliest members of the Institution and who served on the Council for several years. He was educated at University College School, London, from 1831 to 1838. While at school, though he obtained a prize in Latin, his tendency was decidedly towards mathematics, among his competitors in that subject being Sir Henry Doulton, Principal Greenwood, and other men since distinguished in various walks of life. On leaving school he served the usual period of apprenticeship with his father, who was practising in London as an Architect and Civil Engineer. In 1845 he was employed as an Assistant Engineer on the Bristol and Exeter Railway under the late Mr. I. K. Brunel, and afterwards under Mr. (now Sir) Charles Hutton Gregory. Six years later he went to India, having been appointed by the late Mr. James Meadows Rendel an Assistant Engineer on the East Indian Railway.

On arrival in Calcutta Mr. Sibley was placed by the late Mr. George Turnbull, then Chief Engineer, in charge of the Chandernagore District, which was being constructed by Messrs. Hunt, Bray and Emslie as contractors. In August, 1853, he was promoted to Resident Engineer, and placed in charge of the South Beerbhoom District, in which capacity he designed, amongst other works, the bridges over the Rivers Adjai and More. The former, which was built under his immediate supervision, consisted of twenty-nine arches of 50 feet span, and the latter, built under the superintendence of the late Mr. William Clark and Mr. A. C. Bell, acting under Mr. Sibley, consisted of twenty-four arches of 50 feet span. These are the largest brick arch-bridges in India. Mr. Sibley was advanced, in December, 1853, to a District Engineer. About 1857 he was appointed Deputy Chief Engineer under Mr. Turnbull, and in December, 1859, Chief Engineer of the North West Provinces Division, extending from the Kurrumnassa a little above Buxar to Delhi. On the death of Mr. Samuel Power he was, in April, 1868, appointed Chief Engineer of the whole line (Howrah opposite Calcutta to Delhi and Allahabad to Jubbulpore, a length of 1,525 miles) now open throughout, and a Member of the Board of Agency. During his service in the North West Mr. Sibley completed the then largest railway bridge in the world—the Allahabad Jumna, the superstructure, fourteen spans of 212 feet, being designed by Messrs. A. M. and G. W. Rendel, and the foundations by Mr. Edward Purser. This bridge has a railroad above and a carriage- and footway beneath. He

also constructed the Delhi Jumna bridge, twelve spans of 211 feet, he designing the foundations, and the Messrs. Rendel the superstructure. A very handsome brick single-arch bridge of 90 feet span was also built over the Jhirna on the Agra branch by the late Mr. Hamilton Lee-Smith. All the works at Delhi, including those necessitated by passing through the Fort, the Selimghur Bridge, and the handsome station, were designed by Mr. Sibley. While these works will always attest to his engineering ability and skill, his services to the East Indian Railway Company were of the greatest importance, however, in his administrative capacity as a Member of the Board of Agency in Calcutta from 1868 to 1875. He then had control of the engineering, the locomotive, the carriage and wagon, and the telegraph departments, and only those who were intimately connected with him in his work knew how largely the success of the company was due to his powers of organization and hard work, and to the initiation of important reforms which in later years added materially to the prosperity of the line.

In 1869 the honour of the profession was unjustifiably assailed by the Government of India in a Notification, the intention of which was plainly to charge Civil Engineers with recognizing as legitimate the receipt of commissions from others than their immediate employers. Mr. Sibley, with his usual energy, immediately took steps to protest against this insinuation, and, in conjunction with other prominent engineers in India, addressed to the Government a remonstrance couched in the strongest and most indignant terms. The Institution took the matter up, and some correspondence passed with the Secretary of State for India which was printed in full as an Appendix to the Report of the Council for that year.¹

Mr. Sibley left India in January, 1875, on twelve months' furlough, and retired from the service of the East Indian Railway Company on the 14th of January, 1876. After his retirement he built a house on the top of Whitehill, near Caterham, one of the highest hills in Surrey; it was constructed of concrete, and was one of the largest private houses in this country for which that material was used. There he spent the greater part of the summer months. Every winter he went abroad; in recent years always to Teneriffe. He had been a great traveller, having visited many remote and uncivilized regions, and to the last he kept up the habit of constant out-door exercise by taking daily walks. Most of his

¹ Minutes of Proceedings Inst. C.E., vol. xxix. p. 224.

time was now devoted to literary and scientific pursuits, the outcome of which were various contributions to technical journals. He was very musical, and during his travels acquired a good colloquial knowledge of French, German, Italian, Spanish, Portuguese, and Hindostani—a man of remarkable individuality, holding views on most subjects of a decided and rather advanced nature, and in politics a republican. He was clever at making complicated mental calculations, and in working out mathematical problems. He rarely made notes when inspecting works, but on returning to the office, after several days' absence, he would write a report of the inspection, quoting facts and figures from memory. His reports were invariably sent out in his own handwriting, as a rule without alterations or corrections, and it was no doubt partly due to this facility that he was able to get through so much original work. Perhaps his individuality was most marked by his vegetarian habits. At the age of nineteen he became a total abstainer and a strict vegetarian, acting upon the principle that it was not right to destroy animal life or even that which might become animal life.

Mr. Sibley enjoyed perfect health up to the winter of 1890–91, when he had, while in Teneriffe, one or two attacks of shortness of breath, which he attributed to asthma. On returning to England in the spring it was discovered that he was suffering from a pronounced form of heart disease, from which he died on the 25th of October, 1891, at the age of sixty-seven years.

In recognition of his services in India, Mr. Sibley was created a Companion of the Order of the Indian Empire. He left a considerable legacy, for the purpose of founding engineering scholarships and of encouraging native engineering students, to the University of Calcutta, of which he had been appointed a Fellow by the Governor-General in Council on the 19th of January, 1872. He was elected an Associate of the Institution on the 5th of February, 1850, and was transferred to the class of Member on the 13th of April, 1858.

DONALD NICOLL was born on the 25th of April, 1820. The earlier part of his life was spent in trade, which he relinquished to become the owner of sanitary works and the inventor and maker of appliances for the interception and deodorization of sewage, the filtration of water, and other cognate matters. His inventions,

for which he took out numerous patents, were by no means confined to sanitary matters, being spread over a wide field from improvements in fire-escapes to fog-signals for vessels, and electric and telegraph-conductors. In 1849, Mr. Nicoll served the office of Sheriff of London and Middlesex, and subsequently for many years was a representative of the ward of Cornhill in the Court of Common Council. In 1857, he was elected in the Liberal interest Member of Parliament for Frome, which borough he represented for two years, and in 1864, he became Captain of the 29th North Middlesex Volunteers. Some three years later, he successfully laid, in conjunction with Mr. Robert Sabine, ten miles of underground telegraph-conductors, on a system for which he had secured a patent. He was appointed Commissioner for the City of London to the Paris Exhibition of 1867, from which he received a medal and an honourable mention for his exhibit showing the properties of bitumen as an insulating-substance. He was also awarded medals by the authorities of the Exhibitions at Moscow in 1872, and Vienna in 1873.

Mr. Nicoll was the author of several books, among which may be mentioned "Health and its Appliances" (1884), "Underground *versus* Overhead Wires" (1887), and "The Telegraph and Telephone, considered in relation to Economy and Efficiency" (1887), and of numerous pamphlets on various subjects. During the last few years of his life he was Chairman of the Engineering and Sanitary Works Association. He was also a Justice of the Peace for Middlesex and Westminster, a member of the Society of Arts, of the Inventors' Institute, of the Spectacle-makers' Company, and of the United Grand Lodge of Freemasons, Chairman of the Poor Law Amendment Society, and a Life Governor of many of the charitable institutions of London. At the time of his death he was occupied in bringing out a patent for paving roadways with blocks or slabs of hard Australian jarrah-wood, which he claimed to be cheap, cleanly, and safe for horses. He was a man of considerable public spirit and kindness of heart, and took an active interest in many philanthropic movements. In the year 1864 he was awarded a medal by the Royal Humane Society for saving, at the risk of his own, the life of a boy who had ventured on the too-thin ice of one of the Hampstead ponds. Mr. Nicoll died on the 6th of September, 1891, at Folkestone, where he had been staying in the hope of recovering from an attack of inflammation of the stomach. He was elected an Associate of the Institution on the 2nd of December, 1864.

MAJOR-GENERAL FREDERICK SMITH STANTON, R.E. *retired*, was the son of William Henry Stanton, Member of Parliament for Stroud from 1841 to 1852, and was born at Stroud in Gloucestershire on the 21st October, 1832. As a cadet at Addiscombe he early showed great ability, coming out first in his term with the Pollock medal and several prizes; he was gazetted Lieutenant in the Corps of Royal Engineers on the 9th of December, 1850. After the usual course of instruction at Chatham, he proceeded to India in 1853, where he was attached to the Public Works Department of Bengal. His first employment was on the Grand Trunk road, which at that time, when only three or four short lengths of railway had been commenced, afforded the most rapid means of communication between Calcutta and the North-Western Provinces. The section to which he was attached was between the coal district of Raniganj (120 miles from Calcutta) and Benares, a distance of about 300 miles. The rapid passenger traffic was effected by means of carriages each drawn by a pair of country ponies, which, with short stages, performed the journey at the rate of about 8 miles an hour. Stanton's station was on the banks of the Soane, a river 3 miles wide with a sandy bed, across which a causeway was annually constructed.

The monotony of his work was soon interrupted by the outbreak of the mutiny in 1857. The East Indian Railway was at that time open to Raniganj, from which town some of the first detachments of European troops were despatched, four men in each pony-carriage, by the trunk road to Benares. His chief having died, Stanton was left in charge of the whole Road, and in those troublous times was entrusted with magisterial as well as administrative and engineering duties. He was one of the special commissioners appointed by Lord Canning, with summary powers of life and death, to try suspected rebels and mutineers in the disaffected districts, and received the thanks of both the British and Indian Governments for the manner in which he discharged the very responsible duties imposed upon him. In the following May he served as Staff Officer with the Jaineram Field Force, and was present at the affair of Buraon, in connection with which he was mentioned in despatches, and obtained a medal. His bungalow at Sherghatty was the resting place of all the chief Government officials on their journeys up country, and Lord Canning repeatedly partook of his hospitality on such occasions. He was gazetted Captain on the 27th of August, 1858.

Meanwhile the East Indian Railway was being pushed on, and

the Trunk road soon sank into a subordinate position. Captain Stanton entered the Railway Department in 1860 as Deputy Consulting Engineer, his duties being to act as Assistant to the Government Inspecting Officer, who exercised control over the company constructing the railway, under contract, with Government guarantee. In the following year Stanton took furlough. Returning to India in 1863 he was employed on special duty in connection with the Agricultural Exhibition in Calcutta, and subsequently on a committee appointed to inquire into railway extension in the 24-Pergunnahs. He acted in 1864 as Executive Engineer in the Darjeeling Division, during which charge he was detached on military duty with the Doocar Field Force. He soon joined the railway department again, and, after acting from August, 1867, to March, 1868, as Consulting Engineer and Joint Secretary in the Railway Department of the Bengal Government, was transferred to Oudh, where he performed similar duties under the Chief Commissioner of that Province, and in 1869 the Railway Department of the North-West Provinces was added to his charge. In 1871 the Government resolved to undertake the construction of metre-gauge railways in Rajputana, to facilitate the supply of salt from the Great Salt Lake at Sambhar to the North-West Provinces, and to get rid of the vexatious salt-customs barrier. Captain Stanton was selected to take charge as Superintending Engineer of one portion of the railway from Delhi to Rewari and Bandakui, with a branch to Farakhnagar. He was gazetted Major on the 5th of July of the following year. Shortly before the completion of this section the famine of 1873-74 broke out in Behar and Tirhoot; Stanton was sent on emergency duty to construct a short line of 53 miles from the Ganges to Durbhunga in Tirhoot, which he opened for traffic in fifty-three days. The construction of this temporary line, which was carried out at the rate of a mile a day, was, in the words of Sir Richard Temple, then Lieutenant-Governor of Bengal, "an extraordinary achievement in respect of speed. To carry the line over a country intersected by three considerable streams; to make it strong enough to carry 2,000 tons in a day; to open it within the prescribed time, demanded primarily an indefatigable energy, but also professional skill and administrative ability. All these qualities were displayed by Major F. S. Stanton, R.E., the Engineer-in-Chief. Having made this line, he worked its heavy traffic with the same efficiency." The thanks of the Government were given to him for this work, as well as for his services on the Rajputana Railway.

On the completion of the Delhi District of the Rajputana Railway, Major Stanton was appointed in October, 1875, an extra Deputy Consulting Engineer for Guaranteed Railways, and in February, 1876, Engineer-in-Chief of the Tirhoot State Railway then in course of extension. On the 10th of March he was gazetted Lieut.-Colonel, and in the following year acted as Director of the North-Eastern section of State Railways and Joint Secretary to the Government of Bengal in the Railway Department, and in 1880 as Secretary to the Public Works Department of the same Government. In the latter part of 1881 he served as Acting Director-General of Railways and Deputy Secretary to Government, to which office he was permanently appointed in 1882, and which he held for five years. He was gazetted Colonel on the 16th of September, 1886, and in the following February retired from the service with the honorary rank of Major-General, having attained the highest grade in the Public Works Department—that of Chief Engineer 1st class. On returning to England he continued, until his death on the 22nd of January, 1892, to serve on the Boards of the East Indian and the Bengal-Nagpur Railway Companies.

General Stanton won his way to the highest posts in the Public Works Department of the Government of India by professional ability, energy and determination, sound judgment and prompt decision. He never spared himself, and thus inspired his subordinates with the same devotion to work. If somewhat stern in enforcing discipline, it was a proof of his justness and popularity that the best men were always glad to serve under him. In private life he was genial and hospitable, but even with his oldest friends extremely reticent as to his professional and administrative services. He was elected an Associate of the Institution on the 1st of March, 1870.

. The following deaths, in addition to some of those included in the foregoing notices, have been made known since the 31st of March, 1892:—

Honorary Member.

The Right Hon. Lord BRAMWELL, F.R.S.; born 12 June, 1808; died 9 May, 1892. (Diabetic affection.)

Members.

BRUNLEES, *Sir* JAMES, F.R.S.E.
(*Past-President*); born 5 January,
1816; died 2 June, 1892.

HARRIS, ROBERT; died 5 April, 1892,
aged 56.

LANGE, HERMANN LUDWIG; born 10
May, 1837; died 14 January, 1892.
(*Paralysis.*)

MORANT, JOHN HEMPHILL; born 29
April, 1847; died 3 June, 1892.

SMITH, WILLIAM (1866); died 18 May,
1892, aged 68.

WILLANS, PETER WILLIAM; born 8 No-
vember, 1851; died 23 May, 1892.
(*Carriage accident.*)

Associate Members.

CORRY, ALFRED JAMES; born 13 Janu-
ary, 1858; died 4 April, 1892.

HARGREAVES, HENRY EDWARD; died
30 November, 1891.

Associates.

ALLPORT, *Sir* JAMES JOSEPH; born
1811; died 25 April, 1892.

D.Sc.; born 7 July, 1854; died 10
May, 1892.

MAIN, *Professor* JOHN FREDERIC, M.A.,

REID, DAVID; born 11 January, 1841;
died 13 April, 1892.

Information respecting the life and works of any of the above is
solicited in aid of the preparation of Obituary Notices.—SEC. INST.
C.E., 13 June, 1892.

SECT. III.

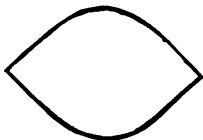
ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS
AND PERIODICALS.*Dimension-Stone Quarrying ; the Blasting Process.*

By WILLIAM L. SAUNDERS.

(Transactions of the American Society of Civil Engineers, November 1891, p. 50.)

The Author describes various systems of drilling for rock blasting, with special reference to the Knox system, of which the purpose is to release stone from its bed by directing the force of a blast to cleave the rock in a prescribed line without injury ; or for splitting large blocks into smaller sizes without waste. If a hand-drilled hole be, as is often the case, approximately triangular, the lines of rupture will follow the direction of the corners.

In the old sandstone quarries of Portland, Connecticut, a blasting canister of diskoid form was tamped in a large circular hole, with its edges in the vertical plane, and in the prescribed line of fracture, and good results were obtained, though at a loss of material from the large hole which was necessary to accommodate the diskoid canister. Straight and true breaks were secured, which followed the line of the disk edges. Again, a square prismatic canister would give two lines of fracture at right-angles. Blasting by lewisings consisted in drilling two, three, or four holes in the line of desired fracture and breaking down the material between them. This was confined to granite almost exclusively. In the Knox system, based on the observation and experience of the foregoing methods, and upon the principles underlying their results, an ordinary round hole is drilled, and then reamed down on two opposite sides, so as to give re-entering angles, the cross section of a reamed hole being like a square with two corners rounded off thus—



The wedge corners are reamed in the line of fracture desired, and the holes being small, very little material is wasted, and very small charges are necessary ; in fact, the smallest charge possible is the best, and preferably slow-burning powder. Hard rocks require less powder than soft, and soft rocks require holes at 4 or 5 feet

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intervals, fired simultaneously by electricity. The tamping in the Knox process should not be directly on the powder, but an air-space should intervene as long as possible consistent with sufficient tamping not to blow out. The fracture then follows the line of direction of the corners of the reamed grooves, which appear first to act as weak points, whence a crack may start, and into this crack the powder gases escape, and act like a wedge in continuing it indefinitely in a straight line to the extent of the force available. In no case should the holes be drilled above $1\frac{1}{2}$ inch diameter in any rock.

The system has its limitations as described, and requires free faces and an intelligent use of the channelling machine when needful.

The Paper is illustrated by diagrams.

W. H. B.

New Formula for Yellow-Pine Posts. By JAS. H. STANWOOD.

(The Railroad Gazette, New York, 1892, p. 76.)

This formula is devised from a plotting of the results of tests on full sized "sticks" at Watertown Arsenal as printed in the U.S. Government Reports.

From the diagram of test-values was deduced the straight line formula $S = 5,000 - 43\frac{1}{3} \frac{l}{d}$ as the average of all the tests. The average of the lowest values in each set of tests gave $S = 4,250 - 43\frac{1}{3} \frac{l}{d}$. This line chanced to be parallel with the first line found. With the latter formula as a basis, the working formula $S = 1,000 - 10 \frac{l}{d}$ gives a marginal factor of nearly 4.25 for yellow-pine posts. If it be preferred not to depart from the usual column formula of the form—

$$S = \frac{K}{1 + \frac{1}{a} \frac{l^2}{d^2}},$$

then the following may be used—

$$S = \frac{4,000}{1 + \frac{1}{2,500} \frac{l^2}{d^2}},$$

which if plotted will be found to represent the average of lowest values.

In all the above formulas—

l = length in inches;
 d = smaller diameter in inches;
 s = pounds.

A Table is added, calculated from the formula $S = 1,000 - 10 \frac{l}{d}$.

Recent experiments by Kirkaldy on wood columns have been applied to the formula, and found to quite well agree therewith.

A diagram of test-values and comparison of Ely's and Shaler Smith's formulas and a calculated Table of safe loads accompany the Paper.

W. H. B.

The Strength of Materials for Railway-Construction.

By — MUSSY.

(Le Génie Civil, vol. xx., 1892, p. 259.)

The Author, from long experience, has been able to formulate the most necessary tests which material for railway construction should undergo. He begins with steel tires used for locomotives and tenders. The tests referred to were carried out upon different tires of Siemens steel made for a railway company between August, 1887, and April, 1890. The specification required tests by falling weight and also by tension. One hundred and eighty-two tires were tested with the weight, and four hundred and five test-pieces by tension. The deflection of each tire was not to exceed a specified minimum with four blows of a weight of 1 ton falling from the height of 16 feet 4 inches. In the tensile tests the lowest average result for the series was required to exceed 33 tons breaking-load per square inch with 16 per cent. extension, and $10.635 R + A = 66$, where R represented the breaking-load in tons per square inch, and A the percentage of extension; no test-piece was allowed to pass in which R was less than 31.75 or A less than 15 per cent. The test-pieces were 7.9 inches long, and 0.79 inches diameter, and they were cut from the outside of the tire. In each test the breaking-load, the percentage of extension, and elastic limit were measured; the latter by means of a pair of compasses. The reduction of area at the fracture was also taken note of. The Author then classifies the tests under the headings: fibrous cup-shaped fractures, fibrous one-sided fractures, and granular fractures.

It appears from Tables which are given that the breaking-load in tons was as follows:— R varied, with cup-shaped fractures,

¹ The values of breaking-load in the French Tables are given in kilograms per square millimetre; this being the case, a constant 0.635 must be used as a multiplier of the value R of the breaking-load in tons per square inch, and the same reasoning applies to the value E .

from 32.75 tons to 37.5, the corresponding extension A varied from 23.5 per cent. to 19 per cent., while the reduction of area S varied from 47 per cent. to 38 per cent., and the elastic limit E varied from 18.6 tons to 21.2 tons.

The figures given in the Tables for the other fractures are somewhat similar, and the general results from the data given in the tests are as follows:—

With fibrous cup-shaped fractures the extension diminished with the increase of breaking-load, but at a slower rate, so that $0.635 R + A$ increased with the breaking-load R ; this sum varying from 75 to 78.

The reduction of area increased with the extension, but almost twice as rapidly; it varied directly with the breaking-load, so that $0.635 R + S$ is a constant approximately equal to 98.

All the tires, in which $0.635 R + S$ was a constant and equal to 98, gave satisfaction when subjected to the falling-weight test. It is not, therefore, surprising that in Germany the sum $0.635 R + S$ is specified as a constant, and a minimum value is stated for R .

In the particular case of tires for locomotives $0.635 R + S$ is a constant of the value 98, and $0.635 E + A$ is a constant of the value 52, or rather more than half $0.635 R + S$. These results are given in a Table. The elastic limit measured by means of compasses is always a little higher than the absolute limit measured by pressure gauges or the elasticity meter used by the P. L. M. Company, and due to Mr. Néel.

It appears that for tires of all degrees of hardness $0.635 R + S$ is a constant, and $0.635 E + A$ is a constant approximately half $0.635 R + S$.

The value of $\frac{E}{R}$ is equal to 0.5 for soft metal, and increases with the degree of hardness to about 0.55. The measurement of reduction of area is essential, as it varies not only with the extension, but also with the elastic limit, or rather with the ratio of the elastic limit to the breaking-load. With the ordinary testing-machines it is difficult to obtain the elastic limit with exactitude, therefore the value $0.635 R + S$ which takes it into consideration is most important.

The constants 98 and 52 are obtained from the fibrous cup-shaped fractures, while the more irregular fractures are due to the fact that either the machine does not give a steady central pull or that there is a defect in the test-piece. Neither the one-sided fractures nor the granular fractures are so satisfactory as the cup-shaped fractures, and the value of $0.635 R + S$ for granular fractures was only 78 in place of 98, while for steels with breaking-loads of from 31.75 tons to 38 tons per square inch the extension was only 16 per cent. in place of 21 per cent. for those steels which broke with a cup-shaped fracture. Tables are then given showing the values of R , A , S , and E for test-pieces, both above and below the normal.

A Table follows, in which the results of tests from October, 1887, to March, 1890, are given with special reference to the greatest and least values of the reduction of area of the test-pieces, from which it appears that $0.635 R + S$ attained a maximum of 103, and descended to a minimum of 87. The Author proposes that the formula $0.635 R + S$ should always be used in specifications, stating at the same time that R must not be below 31.75 tons per square inch. The whole of the Tables apply solely to mild steel locomotive-tires. A great number of details then follow in tabular form, which tend to support the Author's argument, and his conclusion is that the quality of a test-piece may be judged from the value $0.635 R + S$, and that a minimum value for R should be stated which will vary according to the use to which the material is to be put.

E. R. D.

The Working-Stresses for Iron and Steel. By V. CONTAMIN.

(Mémoires et Compte Rendu de la Société des Ingénieurs Civils. September, 1891, p. 275.)

After a brief introductory statement of the character of the stresses to which engineering structures are subject, the Author lays down as a general principle, based on a very thorough study of the subject, and on numerous tests carried out by the Northern Railway of France, the axiom, that when only static forces are considered, the calculated stresses should be less than one-third of the limit of elasticity, while, when all the dynamic conditions and other results of the forces concerned are taken into account, the half of that limit should not be exceeded.

The Author then proceeds to explain the method adopted by the French Railway Company for determining the limit of elasticity of rails by flexure, with gradually increasing loads, and compares the limit of elasticity as determined for the extreme fibres by bending tests with the value resulting from tensile tests of the same material. The following figures have been selected from those given by the Author:—

Weight of Rail per Yard.	Limit of Elasticity by Flexure.		Limit of Elasticity by Tension.	Breaking-Stress by Tension.
	Flange. Compression.	Head. Tension.		
Lbs.	Tons per Sq. Inch.	Tons per Sq. Inch.	Tons per Sq. Inch.	Tons per Sq. Inch.
61.28	32.66	32.31	25.40	45.08
86.69	29.31	32.19	25.40	43.81
86.69	28.83	31.69	{ 25.40 25.08	{ 46.35 47.81

The maximum elongation ranges from 21 to 15·5 per cent. Impact tests are carried out with a monkey falling, in the case of the heavier rails, from a maximum height of about 16 feet 5 inches, and causing a maximum deflection of 1·93 inch.

The following is the chemical composition of the rails in question :—

Weight of Rail.	Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
Lbs. per Yard.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
61·28	0·39	0·3	0·065	0·096	0·019
86·69	0·39	0·3	0·074	0·096	0·020
86·69	0·39	0·6	0·046	0·042	0·027

An investigation of the forces acting on a rail, when the locomotive is in the most unfavourable position and the effects of vibration and of the momentum of the connecting-rods are taken into account, shows that the maximum stresses produced in a 60-lbs. rail, amount to 12·16 tons per square inch in tension, and 15·96 tons per square inch in compression. The greater of these values, the Author points out, only slightly exceeds half the limit of elasticity. In consequence, however, of the continuous increase in the weight of the rolling-stock on their main lines, the company are replacing the 60-lbs. rail by a rail weighing 86·69 lbs. per yard.

Tests made with some of the earliest steel rails, which have been in use since 1867 and 1868, show that their elasticity has not been diminished in the least.

On this account the Author arrives at the conclusion that alternations of tensile and compressive stresses have no detrimental effect on the elastic properties of metals, so long as those stresses remain within the limits of elasticity. Calculations as to the stresses to which carriage and locomotive axles on the Northern Railway of France are subject, prove that such stresses at the worst do not exceed the half of the limit of elasticity.

With reference to the bridges of the railway company in question, tests of samples taken from old bridges, which it has been found necessary to replace or strengthen, also show that the material has not deteriorated from long use. In the construction of their bridges, the company make the joints in such a manner that the rivets are not subject to shearing stress, the whole load being transmitted through the friction between the parts united. This is secured by allowing from three to four times the amount of adhesion actually required, the latter being calculated at 4 kilograms per square millimetre (?) (2·54 tons per square inch), that is to say, one-third to one-fourth of the force required to make the surfaces slide on each other.

The tension bars used have an ultimate strength of 22·86 tons per square inch, with an elongation of 10 per cent.; for angles and tee bars, &c., the corresponding values are respectively 21·59 tons per square inch, and 9 per cent. elongation; for rivets 24·13 tons per square inch, and 28 per cent. elongation.

The very soft steel employed by the company in the construction of bridges, when for any reasons the depth of the girder is relatively small, has a mean ultimate tensile strength of 27·94 tons per square inch, with an elongation of from 24 to 28 per cent. The limit of elasticity of this steel is about 13·3 tons per square inch.

For the main girders a working stress of 4·76 tons per square inch is adopted, but for the transverse girders this is restricted to 3·17 tons, and for the rail-bearers to 2·54 tons per square inch. These figures refer to the net sectional area of the members.

The Author concludes his article with extracts from the official regulations as to the strength of bridges in force in Russia, Austria, Belgium, Holland and England. The Russian regulations are very elaborate.

G. R. B.

The Adaptability of Mild Steel as a Constructive Material.

By A. MARTENS.

(Zeitschrift des Vereines deutscher Ingenieure, 1892, pp. 172, 204 and 236.)

The Author, in discussing the recent reports on the subject,¹ as well as the investigations of Tetmajer and other authorities, summarises and analyses their conclusions at considerable length. The series of Papers is accompanied by comparative diagrams showing the results of the various experiments and the variations of chemical composition, and by Tables of the results of bending tests under different conditions. As illustrating the prejudicial effect of working at "blue heat," samples of basic (Gilchrist-Thomas) steel, which in the cold state were bent to 90°, and straightened again twenty-four times in succession before breaking, were fractured at the seventh bending at "blue heat."

P. W. B.

¹ Minutes of Proceedings Inst. C.E., vol. cvii. pp. 450, 452.

On the Use of Mild Steel.

(Zeitschrift des Vereines deutscher Ingenieure, 1892, p. 280.)

This is a report of the Committee nominated by the Aachen section of the Society of German Engineers, to consider the subject of steel in reference to recently developed processes, and its consequently extended adoption for purposes of construction. The Committee state that they have thought it advisable to confine themselves to general questions and conclusions.

The first point considered was: Is soft or hard steel preferable, under general conditions, for building-purposes; what are the limits of strength which it is desirable to specify, and are any further tests required? The Committee state that, generally speaking, soft steel is to be preferred. For ordinary commercial and industrial purposes, the tensile strength should be between 23·45 and 28·60 tons per square inch, the minimum extension 20 per cent. (in test bars 8 inches in length), and the coefficient of quality (resistance and extension) 508. For bridge-work the tensile strength should be between 23·45 and 27·30 tons per square inch, and coefficient of quality 572. It is not considered advisable to specify any chemical analysis, as the physical properties afford a sufficient index to the composition of the metal, and the result depends not only upon the quantitative identification of the component substances, but also upon their mechanical combination.

In considering if it is advisable to specify not only the class of material but also the precise method and conditions of its production, the Committee are of opinion that the specification must be limited to such general normal conditions for the identification of quality as can indubitably be conformed to, and that any minute limitations are technically impracticable and without result, and commercially injurious.

As to whether any further precautions are necessary in the manipulation of steel (that is, in addition to the methods of working of wrought iron), the only point to be noted is that, unless unavoidable, the material shall not be worked when in the condition of blue-heat.

The Committee finally considered whether any increase in working loads is admissible, and if so, to what extent; and upon this point they are decidedly of opinion that the working load can be increased to 6·35 tons per square inch for live loads, and 7·62 tons per square inch for dead loads.

P. W. B.

On the Metallic Structures of the Future.

By Professor F. STEINER.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereins, 1892, pp. 113, 149.)

The Author, in a Paper read before the above society, discusses two matters which, in his opinion, will receive in future greater attention than hitherto in the construction of bridges, viz., the vibrations caused by the regularly-timed impact of a passing load, and the use of aluminium in an alloy with iron.

If a system of bars, for example a Warren girder, receives in any part a single impulse creating a longitudinal vibration in a bar, such single wave is transmitted by various ways to any given distant point of the system, which, therefore, receives a number of impacts from various directions, either simultaneously or consecutively. If the impulse is repeated at intervals, which are in simple proportion to the time occupied in reaching the given point, it may happen that at such point vibrations of increased and dangerous magnitude occur, or, if the interval is modified, it may happen that the vibrations neutralize each other.

The same applies to transverse vibrations, such as are produced by the regular step of soldiers, by wheels running over the single stones of the pavement or over the joints of rails, and by imperfectly balanced driving-wheels of locomotive engines.

Experiments made on a suspension-bridge at Prague with Fränkel's extension-gauge ("Dehnungszeichner"), are given in proof of the theory. The middle span of the bridge is a continuous girder, supported at five intermediate points from straight chains. A train of ten loaded carts produced in one of the chains a strain of 1.9 ton per square inch, gradually as more carts appeared on the bridge. Quite different was the effect of a troop of soldiers marching in step; the girder made violent transverse and the chain longitudinal vibrations, the quiescent strain in the chain corresponding to this load was less than 1 ton, but the vibratory strain reached 2.86 tons. At the same time no vibrating effect was noticed in the next chain.

After alluding to Professor Robinson's observations and calculations (Ohio Railway Commission, 1883), showing that bridges of a certain span are exposed to danger by passenger-trains, and bridges of another span by goods-trains, on account of their different speed, the Author investigates mathematically the number of vibrations pertaining to girder bridges per unit of time, of a given moment of inertia of the section, modulus of elasticity of the metal, span and weight, and shows that the results agree with those obtained by Bresse and Clebsch, and with observations made. Thus the number of vibrations in a second of bridges of between 32.8 and 328 feet span varies between 6.1 and 1.9 when loaded, and between 15.3 and 2.6 when not loaded. On the other hand,

the number of impulses caused by the balance-weights of the engine wheels, easily calculated with their diameter and the speed, is found to vary for speeds of about 12 to 50 miles an hour between 1.0 and 5.9 per second; in the same way the number of impulses caused by the wheels striking the joints of the rails and calculated from the speed and the wheel-base, varies for the above speeds between 3.08 and 18.56 per second. A comparison of these figures with those given for the number of vibrations of bridges of various spans shows the possibility of danger arising from a certain speed. In reality the conditions are more complicated, because the two cranks attached to the same axle are at right angles to each other, the wheel-bases of a train are irregular, and the number of vibrations of the bridge decreases as the train proceeds on it. The Author gives directions for the investigation of any special case by a graphical method, and then refers to the fall of the bridge at Mönchenstein, near Basel.¹ He calculates the number of vibrations of the bridge, and finds it to be 4.68 per second when loaded, 5.82 when half loaded, and 8.82 when not loaded. The speed of the fatal train was 33 feet per second, the distance between the axles 5.9 feet, and the number of impulses, therefore, 5.6; similar results are obtained with regard to the balance-weights, and the Author thinks that the correspondence between the impulses and the vibrating period of the bridge may have been a factor in the destruction of the bridge. At all events he thinks that from the above theory may follow that it is advisable to try every bridge with various trains and speeds, in order to ascertain those which are dangerous to it.

In the second part the Author reviews the extensive experiments with wrought-iron, Siemens steel, and basic steel, recently made at the instance of an official commission in Bohemia. The commission came to the conclusion that each of the three metals is suitable for bridge-construction, and, in particular, that Siemens steel and basic steel have proved to be of equal value. Experiments at low temperatures were intended, but not made; but the Author gives results obtained by himself with the three metals, and with aluminium basic steel in August, 1891. In all cases the tensile strength was increased, but the elongation and contraction diminished by cold. Relatively good qualities were shown by the new alloy, which had a breaking strain of 29.7 tons, 22 per cent. elongation in 8 inches, and 64.7 per cent. contraction at -76° Fahrenheit, whilst 27.7 tons, 26, and 66.5 per cent. respectively, at $+43^{\circ}$ Fahrenheit. It was proved that in bending slowly, or under the hammer, an injury to the surface detracted much more from the resistance at a low than at an ordinary temperature. The question, however, whether these experiments at low temperature have given useful results, appears to the Author an open one.

Further experiments made at the suggestion of the Author,

¹ Minutes of Proceedings Inst. C.E., vol. cvii. p. 456.

with a view to improve the ingots in respect of their invariably porous condition near the surface and at the core, have so far given very promising results. The alloy contained quantities of aluminium, varying between 0.11 and 0.43 per cent. of weight. The effect of the aluminium was an increase of strength of the alloy, and a complete disappearance of the bubbles in the ingots. While the Author is careful not to draw fixed conclusions from these limited experiments, he thinks that in future aluminium will, probably, play a prominent part as a clarifier of metals used for structures, but, as it is easily affected by acid and alkaline liquids, that the expectations attached to it as a structural metal by itself, will not be realized.

M. A. E.

The Testing of Metallic Bridges. By MAX DE NANSOUTY.

(Le Génie Civil, vol. xix., 1891, pp. 367, 387. 5 Figs.)

The instructions for the testing of metallic bridges, which were prepared by the French Government on July 9, 1877, have now been superseded by new rules issued August 29, 1891. The Author states that the chief points of difference between the old and new rules are as follows. At the date of 1877, steel was used only to a limited extent for such work, and since that date the weight of the rolling stock employed has much increased. A special commission was appointed for the purpose of drawing up the new rules, and note was taken of the present practice in Germany, Russia, and Austria. The new rules apply to girders of all types, and to bridges upon narrow-gauge lines.

The working load of the metal.—For cast-iron the old coefficients have been retained almost intact. For wrought-iron, in place of one single coefficient, which was employed in all cases, several different coefficients are now to be used, which take into account the relation of the maximum and minimum loads, as well as the position of the part under observation.

The nett section is to be taken for tension as well as for compression, so that the areas of the rivet-holes must be deducted from the total section of the part. The stress allowed is less when exerted across the grain than when exerted in the same direction as the grain of the iron.

For steel, the same rules are applicable as for wrought-iron; but the same stress is allowed in the direction of the grain and across it. The quality of the metal is to be such that the rates of load at elastic limit to breaking load is a constant. This rule has special reference to dephosphorized steels. All rivet-holes are to be drilled. For the riveted joints the breaking load is fixed at four-fifths of that specified for the bars.

Load.—Having regard to military transport it is required that

all calculations be made for a standard train, which is to be the same for all railways, with the exception of those of narrow gauge, for which a standard train of smaller weight is required.

The train has been adopted in preference to an evenly distributed load, which may lead to serious errors. The regulations also provide for cases in which a load of 20 tons would come upon one axle. For ordinary road bridges the distributed test-load is still retained, but it is raised to 82 lbs. per square foot, instead of 61·5 lbs. A rolling load is also required which shall be as nearly as possible equivalent to that of the maximum load possible in practice. This is obtained by placing upon the bridge carts of the heaviest type.

Wind-pressure.—A uniform pressure of 55 lbs. per square foot must be allowed for when the bridge is not loaded, and a coefficient of reduction is allowed for surfaces which are not directly exposed to the force of the wind. When the bridge is loaded with the test-weight, the wind-pressure is to be calculated at 35 lbs. per square foot on the bridge and upon the train, the surface of the latter being taken as 10 square feet per lineal foot. In the case of road bridges no account will be taken of the load upon the bridge.

Buckling.—All parts in compression must be designed to resist buckling.

Bending.—All tests for bending must be made with the standard train, or with the special test-train if that is definitely settled. The measurement of depression under the test-load is obligatory, and rules are given which control the clear space to be left between the trains and the sides of the bridge. The regulations themselves are then given in full, and part are specially applicable to bridges which carry canals.

According to the regulations all existing structures in France must be inspected in accordance with these rules before January 1, 1893.

E. R. D.

The Testing of a Wrought-Iron Bridge over the Charente.

By — CUËNOT.

(Annales des Ponts et Chaussées, July 1891, p. 1.)

The Author of this Paper gives, in complete detail, the results of a series of experiments which were made to determine the elastic strain in each member of a Warren girder under a steady load, and under a rolling load travelling at a speed of 35 kilometres (22 miles).

The bridge in question carries a single line of railway (of 1-metre gauge) over the Charente in two independent spans of 35 metres (115 feet) each, the main girders having a length of 36·12 metres between the points of support, and a depth of 3·36 metres. The diagonal braces form, with the lower chord, a series of seven

isosceles triangles measuring 5.16 metres at the base, and 3.79 metres length of side. From the apex of each triangle a vertical suspender divides the base into two panels of 2.58 metres, at which uniform distance the cross girders are spaced, dividing the floor into fourteen equal panels. The members are constructed of plates and angle-bars, with riveted connections, the upper and lower flanges being of tee-section, with a rather deep web-plate. The Paper gives the dimensions of every detail, the estimated weight of each member and panel, and the calculated stress in each member due to the actual distribution of the dead load.

For the purpose of the test, the rolling load consisted of two engines weighing 22.3 tonnes (21.95 tons) each, and a train of 13-tonne waggons, whose length was more than sufficient to cover the bridge. To test the strain in the flanges, the train was made up with the two engines in the middle, and with their heaviest ends coupled together in the centre of the load so as to produce the greatest bending moment; and the train was brought successively into such positions as would give the greatest stress in each panel of the upper and lower flanges. But in testing the diagonals of the web, the two engines were placed at the head of the train so as to produce the greatest shearing-stress; and the train was brought into such positions as would give successively, the greatest tensile and compressive stress in each diagonal. At each position of the train, the elastic yield in every member of the girder was measured by means of a Manet extensometer, thirty of these instruments being simultaneously employed on the different members of the bridge.

In this instrument the elastic extension or compression on 1 metre length of bar, is magnified forty times in the motion of the index finger, which travels over a segmental arc or scale, divided into spaces of 2 millimetres (0.079 inch), so that each division corresponds to an extension of $\frac{1}{20}$ millimetre; and calibrating the instrument for an assumed modulus of 20,000, each division would correspond to a stress of 1 kilogram per square millimetre (0.635 ton per square inch), while the stress might be read to $\frac{1}{10}$ kilogram by estimation.

The stress in each member of the girder, as deduced from the observed elastic strain, is recorded in the Paper, and was arrived at by taking the mean of the readings observed during repeated tests of each of the main girders. In the first series of experiments the train was allowed to rest for a quarter of an hour in each of the successive positions before described, and the readings were then taken for each member of the girder as shown by the several instruments.

At the same time the stress in every member was calculated in the usual way, for each position of the train, from the known loads on the several axles; and the calculated stresses are compared with those deduced from the observed strains. The general result obtained from these experiments with a stationary load was that the stress read off from the instruments was somewhat less than the

calculated stress—a discrepancy which would be corrected at once by calibrating the instruments to a slightly modified modulus of elasticity. As regards the flanges, however, the observed difference was greater in the lower than in the upper flange, while in the diagonals the greatest difference was found in the inclined end struts, whose observed elastic strain was very considerably less than the amount calculated. In the vertical suspenders the observed was sensibly equal to the calculated strain.

In the second series of experiments, the readings were taken during the passage of the same train at a speed of 35 kilometres an hour; and a comparison of the elastic strains observed during these tests, with the readings taken under the stationary load, gives the means of measuring the ratio between the stresses due to the passing load, and those due to the same load at rest.

On the average, the increase of stress due to the dynamic action of the moving load was found to be 22 per cent.

Mr. Souleyre, in his Memoir upon the dynamic action of rolling loads, contained in the *Annales des Ponts et Chaussées* of October, 1889, calculates that, for points situated at one-fourth and at one-half of the span, the coefficient of augmentation will be 23 per cent. and 10 per cent. respectively in a bridge of 30 metres; or 22 per cent. and 10 per cent. in a bridge of 40 metres, the assumed speed being 36 kilometres. The Author regards these calculations as satisfactorily verified by the experiments, which demonstrate the importance of the dynamic effects produced by a rolling load, and the necessity of taking them into account in determining the sectional area for the various members of an iron bridge.

T. C. F.

✓ *Road-Bridge over the Rhone at Lyons.* By MAX DE NANSOUTY.

(Le Génie Civil, vol. xx., 1892, p. 289.)

Description.—This bridge, occupying a very important position in the City of Lyons, has lately been constructed by the Municipal Council to replace a suspension bridge which was only suited to light loads. It is called the "Pont du Midi."

It consists of three metallic arches hinged at each springing resting on piers and abutments of masonry. The total length is 678 feet, and the width between parapets 65·6 feet, comprising a roadway of 36·1 feet in width, and two footways of 14·75 feet each. The maximum clear headway under the bridge from low water is 30·5 feet in the middle arch, and 27·4 feet in the side arches.

Each span consists of eight ribs carrying equidistant vertical posts which carry the floor. The floor is composed of cross girders, trimmers, and buckled plates. The roadway is paved

with wood blocks on concrete, and the footways with asphalt. Architectural decoration has been largely applied, both in carved stonework at the heads of the piers, and in cast-iron on the exterior of the spans.

The side spans measure 205 feet between centres of springings, and the middle span 224·7 feet. In the former the rise is 14·7 feet, and in the latter 17·7 feet. The depth of the rib increases from the crown, where it is 3·6 feet to the springing, where it is 4·9 feet in the middle span, and 4·6 in the side spans. The rib is composed of a web slightly over $\frac{3}{8}$ inch thick in two plates jointed along the mean fibre of the rib and flange plates also $\frac{3}{8}$ inch thick, but varying in number according to the stress, 19·7 inches wide, united to the web by angle bars $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{3}{8}$ inch. Parallel to the flange plates along the mean fibre of the rib is a plate on each side 4 inches by $\frac{1}{8}$ inch, united to the web by angles 3 inches by 3 inches by $\frac{1}{8}$ inch, with a liner plate under the angles $8\frac{1}{2}$ inches by $\frac{1}{8}$ inch. The steel pins, on which the ribs rest at the springings, are $7\frac{7}{8}$ inches in diameter. The ribs are diagonally braced along the surface of the intrados, and transversely and diagonally braced in vertical planes at each vertical. The verticals are 9·8 feet apart, and consist of four angle bars 3·3 inches by 3·3 inches by $\frac{1}{2}$ inch riveted back to back with $\frac{1}{8}$ -inch plates between them. The trimmers resting on the verticals are plate girders, with web $19\frac{1}{2}$ inches by $\frac{1}{8}$ inch, and angle bars $2\frac{3}{4}$ inches by $2\frac{3}{4}$ inches by $\frac{1}{8}$ inch. The cross girders are riveted to the trimmers, and 3 feet 3 inches apart. They are plate girders with web $12\frac{1}{2}$ inches by $\frac{1}{8}$ inch, and angles $2\frac{3}{4}$ inches by $2\frac{3}{4}$ inches by $\frac{3}{8}$ inch. Secondary trimmers unite the middle of the cross girders, and have the same section. The buckled plates are galvanised, $\frac{1}{2}$ inch thick under the roadway and $\frac{3}{8}$ inch under the footways.

Material.—The material employed was steel with breaking strength of 27·2 to 29·8 tons per square inch, and an extension of not less than 24 per cent. Limit of elasticity fixed at 15 tons.

Calculations.—The methods employed were those of De Dion and Eddy, which gave almost identical results. A variation of $\pm 30^\circ$ Centigrade was allowed for. The permanent dead-load provided for was 17 cwt. per running foot with a surcharge of $61\frac{1}{2}$ lbs. per square foot, and for rolling load four lines of carriages weighing 16 tons each on two axles. The maximum stress in any part of the arch under the most unfavourable conditions of load and temperature is 6·8 tons per square inch.

Construction.—The piers are founded at 42·6 feet below low water to protect them from scour, and the abutments at 8·2 feet. Borings were made by means of sheet-iron tubes, within which a kind of sand pump drew up the materials (sand and gravel), and which was loaded and rotated to make it descend. The piers were founded by caissons, using compressed air. Two accidents happened at one pier, where in one instance the pressure was suddenly taken off to facilitate the descent of the caisson, and

the result was a sudden descent with a cant to one side which could not be rectified, and where at another time a sudden flood broke down the cofferdam of iron plates with timber struts above the caisson within which the masonry was in progress. In the latter case a concrete cofferdam was improvised to complete the work. The abutments were founded without any cofferdam by pumping. There was a head of water in the river of nearly 10 feet, and only a bank of gravel between the excavation and the river. Each abutment took two months' work night and day. At one of them three centrifugal pumps of 8, 10, and 12 inches were required; at the other two of 8 inches sufficed. The arches were erected on scaffolding.

Cost.—The cost of the works has been £76,000, divided as follows:—Masonry and paving, £36,000; iron and steel, £38,640; miscellaneous, £1,360. The weight of metal is 125½ lbs. per square foot of the bridge, or deducting for ornamental work and bed-plates 107·5 lbs., and the cost of it in place 19s. 2d. per square foot.

The article is fully illustrated by one two-page engraving and eight smaller engravings.

C. F. F.

On Subaqueous Rock-Boring in Reference to the Danube Improvement Works at the "Iron Gates."

By MICHAEL VON KÖNYVES-TÓTH.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten Vereines, 1891, p. 147.)

In the works for the improvement of the navigation at the lower rapids of the Danube, which involved the removal of the rocky bed to varying depths, the employment of explosive material was, on account of the small proportion of effective work in such shallow blasts, deemed undesirable; and after the consideration of many proposals, it was finally decided to adopt a mechanical arrangement by which the rock is chiselled and broken up just as a stone surface is worked by a mason. This "rock-breaking" plant, designed by Mr. Thunhart and the Author, is mounted on a vessel (called, from its functions, the "Sziklatörő") the iron hull of which is 114 feet 10 inches in length, 21 feet 4 inches beam, and 8 feet 3 inches total depth; the normal draught being 4 feet 3 inches. On the longitudinal axis are mounted six elliptical caissons, at distances of 9 feet 10 inches centre to centre. These caissons, which are open above and closed below, measure 7 feet 3 inches on the major axis and 4 feet 3 inches on the minor axis, and are suspended on framings between guides, so that they can by hydraulic pressure be raised or lowered as required to the ordinary maximum working depth of 13 feet below the water surface. They are, however, provided with an extra ring, so that

in case of necessity the attachment of this ring would increase the working depth to 17 feet. In each caisson there is a steam-hammer with variable stroke, and in the lower framing of the caisson are bearings for a cross-cut steel chisel $9\frac{1}{4}$ inches diameter. The working pressure is 73.5 lbs. per square inch, and the hammer delivers from 100 to 150 blows per minute; the effective work of the chisel on the rock averaging about 21,690 foot-lbs. The workman in each caisson is able easily to reset or change the chisel, to raise or lower the caisson, to alter the stroke of the hammer and regulate speed and power, or to stop; and he can also test the progress being made upon the rock.

The vessel is moored between two pontoons securely anchored up and down stream and to either bank, so that there is a clear working length of about 165 feet. Each setting breaks up the rock to about 12 inches diameter at each caisson and to a depth of from 4 to 12 inches, according to the hardness of the material. The operation finished, the vessel is re-moored 12 inches in advance, and so on to the working limit, when it is returned to its original position and then shifted 12 inches laterally to resume the same process on parallel lines. At the average power as above and minimum rate of work, the gross work per chisel per hour would be $21,690 \times 100 \times 60$, or approximately 130,000,000 foot-lbs.; and taking the average daily effective work as only 50 per cent., this would be equal to 65,000,000 foot-lbs. per hour. At this rate of work the quantity of rock removed is approximately 2 cubic yards per hour. The daily cost of working (ten hours)—including all intermediate mooring and preparation as well as renewal of machinery and tools—averages £9 11s. 8d., so that the maximum cost is 9s. 7d. per cubic yard. The whole surface being completely disintegrated the current removes all the loose material without the necessity for any further process in clearing the débris. The process is not adapted for the removal of great masses of rock, but for surfaces of moderate depth, so that the impact of from 11,000 to 22,000 foot-lbs. per blow is quite sufficient.

In a rock-boring plant designed by the same engineers, the hull of the vessel is similarly constructed; but to secure the greater rigidity required for the drills, the vessel has, in addition to the anchors, two pilot-frames which grip the bed securely at each end, while the boring-frames being hung by chains are independent of any small movements. The caissons are constructed as diving-bells, with working-chamber 14 feet 9 inches high. The caisson being sunk to within 2 feet or 2 feet 6 inches of the surface of the rock, is secured in position by four steel spindles lowered by hydraulic power, and the boring-frame is then further lowered so that the full weight—about 10 tons—rests on the four Fröhlich drills with which it is provided. These drills are worked by hydraulic power at a pressure of 60 to 90 lbs. per square inch. When the holes are sufficiently deep the dynamite charges are inserted and connected, the caisson lifted and shifted to the next position, about 10 feet further along the stream. The five caissons

therefore drill twenty holes, each shift occupying from one to one and a half hour. Upon completion of the first row the vessel is shifted laterally, and the parallel lines worked on. The vessel is then moored in a place of safety, and the whole of the mines are sprung simultaneously.

The Author then proceeds to theoretical investigations of explosive action and to a comparison of the same with mechanical work; the former being essentially adapted to the removal of masses of rock and the latter for surfaces. The quantity of dynamite sufficient to remove one cubic yard of material of the consistency of the rock at the "Iron Gates" is 1.76 lbs., the effective energy of which is approximately 2,170,000 foot-lbs. The mechanical work equivalent to this result is fifteen times greater, or about 32,500,000 foot-lbs.

P. W. B.

Niagara-Falls Power Plant.

(The Electrical World, 1892, p. 85.)

In this article an account is given of the present state of the works, and the probable arrangement of machinery to be installed later on. The main tunnel, which will form the tail-race for the turbines, was begun in October 1890, and is intended to be finished in July of this year. It will be brick-lined throughout, and will be 18 feet 10 inches wide, and 21 feet high. The tunnel is being driven from three points, namely, from the outlet below the falls, and from two shafts 260 and 196 feet deep respectively. The grade is $\frac{7}{16}$ per cent. The total capacity of the plant will be 100,000 HP. obtained from a series of turbines of 2,500 HP., and possibly 5000 HP. each. The turbines will be placed on the American side of the river, about a mile above the falls, and part of the power is to be utilized in the immediate neighbourhood where mills are to be erected. The rest will be transmitted by compressed air and electricity to greater distances. No wire-rope transmission is contemplated. Each mill will have its own vertical shaft and turbine, with tail-race connected by a service tunnel to the main tunnel. The water will be conveyed to the turbine by a separate supply-pipe entering the turbine wheel from below, so as to balance the necessarily great weight of the wheel and vertical shaft. The available head of water is 130 feet. At present plant for 15,000 HP. is to be erected, some for driving air-compressors, and some for dynamos. The air-compressors will have two horizontal cylinders at right angles, their pistons being driven from a single crank at the top of the turbine shaft. The dynamos are also to be direct driven, the armature being mounted on the top of the turbine shaft. Whether the system of transmission is to be three phase, or single alternating, has not yet

been decided. The pressure will probably be 10,000 volts on the line to Buffalo. Transformers will reduce it to 1,000 volts for distribution within this city.

G. K.

Louvain Water-Supply. By VICTOR J. VAN LINT.

(Annales de l'Association des Ingénieurs sortis des Écoles Spéciales de Gand, 1892, p. 179.)

The new water-supply of Louvain was inaugurated on the 7th of September, 1890. The supply is derived from shallow wells sunk in the water-bearing gravel of the district. The works comprise five draw-wells and one central well. The draw-wells are 23 feet deep, built of masonry resting on perforated iron curbs 10 feet high. The central well is brickwork, 19 feet 6 inches deep, and 44 feet in diameter.

The conveyance of the water from the draw-wells to the central well is effected by siphons which are set in action by steam-exhaust. The water thus collected to the central well is forced by steam-pumps into an elevated brick reservoir, 65 feet in diameter and 16 feet deep, vaulted over and covered with earth, in order to maintain the water at a uniform temperature.

Electrical communication between the service-reservoir and the pump-house is established with a view to commanding a good fire-service rapidly. The population provided for is 50,000, the estimated consumption being 27 gallons per head per day.

J. H. T. T.

*Three Papers on Australian Irrigation.*¹

By W. W. CULCHETH, M. Inst. C.E.

The first of these Papers was read before the Victorian Institute of Surveyors in April, 1885, at which time the subject of irrigation was engaging a constantly-increasing share of public attention in Australia, and the object of the Author was to show how the available supply of water could best be turned to good account. Most of the rivers in Australia, he says, are nearly, if not quite, dry in the hot season, and whenever that is the case it is believed that perennial irrigation could only be effected by storing the surplus waters in reservoirs.

That, however, would be a very expensive system, as, judging from some existing works, it might be expected to cost not less than £40 per irrigable acre. The popular demand for a scheme, or

¹ The originals are in the Library of the Inst. C.E.

schemes, to irrigate the greater part of the northern plains of Victoria, is too large to be practical, and at the most only a small portion of those plains can be irrigated because of the insufficiency of the water-supply. As an example of a feasible scheme, a project is described for irrigating about 238,000 acres (372 square miles) of the Tragowel Plains by diverting water, especially in times of flood, from the River Loddon into four canals running along the highest ground with branches at convenient points. These four canals when full would carry 555 cubic feet per second. They would be 117 miles in length, with twenty-eight branches having an aggregate length of 178 miles, and provided with regulators to control the distribution of the water. The land-owners themselves proposed to carry out this work, the estimated cost of the whole scheme being £164,588, or less than 14s. per acre.

Numerous reasons are alleged in favour of such works being always constructed by the landowners, and objections urged against the demand for their being carried out by the State, while the utmost caution is recommended in dealing with proposed schemes in order to avoid very considerable loss of public money.

The second of the Papers was read before the same Institute a year later, by which time the subject had increased in importance, and the proposal that the State should advance money freely for irrigation works on loan had been accepted. It was proposed by some that the State should even go a step further and carry out all head works, making no charge for them; but the Author, who had charge of the irrigation works in Rajputana for several years and founds his objections on Indian experience, adduces further evidence to prove the desirability of avoiding artificial storage so long as any other means of obtaining a supply of water is available.

Of ten such works in Bombay and in Rajputana, which irrigate 18,100 acres, and on the construction of which £901,677 had been expended, there are eight in which the annual working expenses exceed the total revenue, while the profit in the other two instances averaged only 1·38 per cent. on the capital outlay. On the other hand, there are upwards of 12 million acres irrigated in India by means of river canals at an average annual cost of 3s. 8d. per acre, and in some parts the annual value of the crops will soon equal the whole outlay on the works.

Estimates based on the belief that a depth of only 6 or 8 inches of water per annum need be allowed for the whole irrigable area are very misleading and are disproved by Indian experience. In Rajputana the results of measurements made under the Author's direction showed that (exclusive of the loss from the reservoirs by evaporation and other causes) the average depth of water used per annum during five years was 2 feet 3 inches from the Bhir reservoir, and 2 feet $\frac{1}{4}$ inch from the Bulad reservoir, while the actual quantity of water lost from these reservoirs, inclusive of evaporation, etc., was respectively equal to depths of 4 feet 4 inches and 5 feet 1 inch over the whole irrigated areas. The

loss from the small Rajaoosi reservoir, which irrigates 196 acres, was equivalent to the high average of 11 feet $\frac{3}{4}$ inch.

In the Colony of Victoria a considerable supply of water may be drawn from the Murray river. The Cohuna, the Koondrook, and the Murrabit schemes, taking their supply from this river, will depend more or less on pumping. The Leaghur and Meering, the Twelve-mile Creek, and the Bacchus Marsh schemes will obtain water by gravitation from other Victorian rivers, and seem likely to be successful within a short time, but they are small schemes. The Author advocates drawing a large supply of water from the Murray river (the boundary between New South Wales and Victoria), and distributing it by means of a large canal 400 miles in length. If a weir were erected across this river at the joint cost of Victoria and New South Wales, a canal on each side of the river might be constructed.

Large and difficult works, if they are to be carried out at all just now, must be undertaken by the State, but, judging from experience of the waterworks recently constructed, there is not a good prospect as regards the payment of interest on loans by the State. Small works can best be carried out by the landowners themselves, and works of moderate size would usually have to be carried out by several landowners combining for the purpose. Small irrigation schemes, being less costly in proportion to the area benefited, generally pay better than large schemes.

The third Paper was read in 1890 at the Melbourne Meeting of the Australian Association for the Advancement of Science. An abstract only is published giving the Author's views regarding the best means for making irrigation works in Australia remunerative. For the construction of these, several trusts or companies had been started in the Colony of Victoria on a system which seemed likely to lead to the best results; but finding themselves in difficulties they were at that time asking for concessions from the Government which ought to be the subject of a special inquiry in each case.

The Papers are supported by some interesting details of Indian irrigation, given as an Appendix in three Tables.

O. C. D. R.

*Irrigation in India ; its Lessons for Australia.*¹

By W. W. CULCHETH, M. Inst. C.E.

Irrigation has been practised in India for centuries. During the last three quarters of a century the British Government has kept records of the operations, and the following facts have been prepared almost wholly from official documents; the Author having during several years had charge of the irrigation works in Rajputana.

¹ The original is in the Library of the Inst. C.E.

IRRIGATION WORKS
Result of operations during

Class of Work.	Name of Work and Provinces.—M. Madras; Bo. Bombay; S. Sind; P. Punjab; Bn. Bengal; N.W. North Western Provinces.	Year when Irrigation commenced.	Lengths.	
			Canals.	Distributaries.
A. Old works the whole cost of which is not known	{ Inundation canals. { Lower Indus S. Upper Indus and its tributaries } P. Western Jumna Canal P. Cauvery Delta works M. Minor works	Old works restored and ex- tended by the British Government	Miles. 5827	Miles.
			1,618	129
			279	895
			428	1,250
			157	648
Total of Class A. . .			..	..
B 1. Works con- structed en- tirely by the Government and expected to be re- munerative	{ Bari Doab Canal P. Ganges Canal (<i>Old Works</i>) . . N.W. Godaveri Delta works M. Kistna Delta works M. Minor works	1859 1854 before 1850 before 1860 ..	354	1,020
			656	3,674
			506	1,718
			312	750
		..	..	..
Total of Class B 1. . .			..	..
B 2. Do. do. Re- munerative	{ Sirhind Canal P. Lower Ganges Canal (<i>New Works</i>) . . N.W. Agra Canal N.W. Sone Canal Bn. Mutha Reservoir (Lake Fife) . Bo. Minor works	1882 1878 1874 1874 1874 ..	536	3,035
			345	906
			109	558
			367	1,167
		..	88	67
		..	..	..
Total of Class B 2 . .			..	..
C. Works not likely to be re- munerative under existing circumstances	{ Orissa Canal Bn. Midnapore Canal Bn. Kurnool (Soonkesala) Canal . . M. Minor works	1866 1866 1871 ..	232	718
			72	283
			190	313
			10	207
		..	..	..
Total of Class C. . .			..	..
Grand Totals			..	..

¹ The value of the crops is incomplete, this information not being given for the Canal, which gave a net return of 21 per cent. on the cost of the works, which was

² Cawnpore and Etawah branches included.

³ Cawnpore and Etawah branches being Old Works are transferred to Class B 1.

⁴ Storage works of 13,078 million cubic feet included.

⁵ This sum does not include works in progress or in abeyance.

IN INDIA.

the year 1887-88.

Capital Outlay.	Area Irrigated.	Value of Crops raised by Irrigation.	Receipts from Water-Rates, &c.	Add Share of Land Revenue.	Net Returns Deducting Working Expenses.	Percentage of Returns on Capital.	Average Water-Rate per Acre.	Average Cost of Works per Acre Irrigated.
£	Acres.	£	£	£	£		s. d.	£
1,132,842	1,040,754	2,081,508	11,798	154,286	90,990	8.03	0 3	1.09
143,808	643,520	1,644,589	41,760	67,719	20,507	14.26	1 4	0.22
1,058,489	237,821	825,239	105,101	5,140	51,067	4.82	8 10	4.45
177,583	937,634	not stated ¹	225,401	65,277	256,248	144.30	4 11	0.19
520,912	198,424	731,873	68,534	26,820	71,612	13.75	6 11	2.63
3,033,634	3,058,153	5,283,209	452,594	318,742	490,424	16.17	..	0.99
1,613,602	473,465	1,642,924	131,822	39,390	118,139	7.32	5 7	3.37
3,389,243	837,375	2,994,516	264,433	65,084	189,168	5.58	6 4	4.68 ^a
1,233,048	608,696	not stated ¹	12,433	193,473	140,513	11.40	0 5	2.03
792,126	387,505		7,498	139,195	104,915	13.24	0 5	2.04
899,520	352,325		48,854	55,907	70,557	7.84	..	.. ^b
7,927,539	2,659,366	5,098,895	465,040	493,049	623,287	7.86	..	2.98
3,524,579	487,506	1,691,646	105,747	..	50,765	1.44	4 4	7.23
2,429,420	235,471	713,778	62,668	..	16,858	0.69	5 4	10.32
898,901	124,557	325,932	48,327	..	22,280	2.48	7 9	7.22 ^d
2,589,081	315,380	631,340	81,017	..	5,782	0.22	5 2	8.21
613,064	8,145	181,713	19,258	..	12,483	2.03	..	.. ^e
2,619,762	333,493	816,434	68,717	11,869	26,984	1.03	..	.. ^e
12,674,807	1,504,552	4,360,843	385,734	11,869	135,152	1.07	..	8.42
2,301,463	109,596	128,895	23,547	..	Deficit. -26,698	Deficit. -1.16	4 4	21.02
844,557	65,864	131,728	24,607	..	- 432	-0.05	7 6	12.82
2,165,546	21,927	24,833	5,503	..	- 8,866	-0.41	5 0	98.76
539,618	18,178	27,177	4,385	1,224	- 1,788	-0.33	..	.. ^f
5,851,184	215,475	312,633	58,042	1,224	-37,784	-0.65	..	27.15
29,487,164 ^a	7,437,546	15,055,580 ^a	1,361,410	824,384	1,211,079	Average 4.11	Average 3 8	Average 3.96

Madras Presidency generally. The "Minor Works" include the Eastern Junction £311,655.

^a Storage works in Rajputana included.

^b Capacity 3,283 million cubic feet. Water largely used for domestic purposes.

^c Works storing 7,721 million cubic feet included.

^d The value of the crops in the Madras Presidency is not included in this total.

The works now in operation represent in the aggregate about 8,000 miles of large canals with 24,000 miles of distributaries, and besides these canals there are numerous reservoirs having a total storage capacity of over 28,000 million cubic feet with their corresponding distributaries. The area irrigated in 1887-88 by the works of which complete accounts are kept was nearly $7\frac{1}{2}$ million acres, and the capital invested in them amounted in round numbers to £31,500,000. Nearly five million more were irrigated from works of which no capital accounts are kept, so that altogether more than 12 million acres were under irrigation.

On the aforesaid $7\frac{1}{2}$ million acres the value of the crops in 1887-88 (exclusive of those in the Madras Presidency) exceeded £15,000,000, and the revenue derived directly from water-rates and some minor sources (navigation dues, mill-rent, etc.) amounted to about £1,400,000, the average having been at the rate of about 3s. 8d. per acre; but in some districts, as on the lower Indus canals and in the Godavari and Kistna Deltas, the water-rate is merely a nominal one ($2\frac{3}{4}$ d. to 5d. per acre), the bulk of the charge being included under the head of and collected with the land revenue. On the other hand, much higher rates prevail in the Bombay Presidency, where 18s. and 20s. per acre are not uncommon; but many of the works there are storage-reservoirs, and to a great extent protective works, in which the water is stored from year to year so that it may be available in a bad season.

The cost of the works per acre of land actually irrigated varies very much, because it often happens that only a portion of the land commanded by the canals uses the water. In the North Western Provinces only about one-third, in other cases one-fifth, and in the Bombay Presidency only about one-sixth of the irrigable land is actually irrigated; but under ordinary circumstances the average cost may be taken at about £3 per acre. The works in the Bombay Presidency—mainly storage—average about £21 per acre.

The quantity of water used in irrigation is much larger than is sometimes supposed. A depth of 8 or 10 inches is often estimated as sufficient, but on the Eastern Jumna canal, a very old work which irrigates 176,243 acres, and has given some of the best results in Northern India, the average depth of water actually used per annum has seldom been less than 2 feet 6 inches. On the Ganges canal it has been about the same, and on the Agra canal, which is a modern work, having been opened in 1874, the average was 5 feet 6 inches in 1879-80, and 3 feet 6 inches in the following year, while it exceeded 6 and 7 feet on some of the distributaries.

A Table is annexed showing many interesting details respecting the extent, cost, receipts, etc., of the most important irrigation works in India.

O. C. D. R.

*Hydraulic-Main Arrangement for Dispensing with the
Dip-Pipe Seals of Gas-Retorts.* By ULYSSE ANDRÉ.

(Société Technique du Gaz en France, 1891, p. 192.)

The undeniable advantages of removing the dip-pipe seals, which have led gas engineers to seek a solution of this problem, are the following:—Improved illuminating power, increased yield of gas, less carbon deposits and naphthaline, better utilization of the heats, longer life of the retorts, fewer stoppages in the ascension pipes, etc. In the arrangement referred to, the hydraulic main is divided throughout its whole length into two equal parts by a partition extending to within 6 inches of the bottom, and the dip-pipes are fixed in the front division. The main is also divided, by transverse partitions, into as many sections of two compartments each as there are dip-pipes; the transverse partitions in the front portions stop at such a distance from the top of the main as will leave sufficient room for the passage of the gas from one section to another and to the outlet pipe, the upper edges of these partitions being all at the same level. A pipe, containing compressed gas at a constant pressure from a small gas-holder, passes along the front of the hydraulic main and communicates with each of the compartments of the main, into which the gas passes from the retorts, and with each of the back compartments, by means of three-way cocks. Each cock is manipulated by a chain, counterbalanced at one end and fixed at the other to the corresponding retort mouth-piece, so that when the cross-bar does not press on the cotter, the counterbalance not being held fast acts on the key of the tap opening a passage for the gas in the pipe, which passes into the back division corresponding to the retort in question, causing a pressure upon the liquid and driving a portion of it into the front compartment, where it rises and seals the dip-pipe, cutting off the communication between the retort and the main. When the retort is closed, the cross-bar returns to the position serving to stop the lever, and the chain, acting on the key of the tap, establishes the communication between the back compartment and that containing the gas coming from the retort; the pressure then becoming equal in the two compartments, the liquor in them becomes level and the dip-pipe is unsealed. Each back compartment is fitted with a siphon through which the excess of liquor flows when the retort is in action, the level being so adjusted that, when the pressure is turned into the back compartment, the liquid passes from it into the front below the partitions. Where an exhauster is used the difference between the liquor-levels should be adjusted so as to guard against a casual stoppage of the exhauster.

The system may be applied to any existing hydraulic mains, but, for new ones, a considerable economy may be effected by using a rectangular cast-iron main fitted with as many U-shaped receivers as there are retorts, each receiver being divided into two compart-

ments by a partition between the legs and parallel to them. The two compartments are of unequal length, the dip-pipe being fixed in the longest one, which is connected to the main. The dimensions should be such that the space between the main and the receiver is sufficient for the flow of the gas, an opening for cleaning being arranged at the upper end of the shortest leg.

This arrangement is very simple, consisting only of a three-way valve with a counterbalance and chain. No attention is required, as the valve is put automatically into action by opening or closing the retort. If, on opening a retort, the key of the corresponding tap is not acted upon by its counterbalance, the closing-lever does not act, and the stoker would be unable to withdraw the cross-bar; or if, when closing a retort, the key does not move, the cross-bar will not occupy its proper position, the catch being so fixed to the chain that it cannot be easily set free, the only disadvantage being that the dip-pipe remains sealed while the tap is being loosened. Each retort having a siphon into which the tar flows, the tar has only a short distance to travel and has not time to thicken; should, however, the hydraulic main become stopped the work would not be interrupted, as the liquid would find another outlet through the openings at the upper parts of the main, and, if a receiver becomes full, the overflow would take place through the adjoining receivers. Again, if the exhauster should stop, the pressure in the hydraulic main would be the same in both divisions of each compartment, and the level of the liquor would not change. The seal of the dip-pipes should be adjusted so that, if the exhauster should stop while a retort is open, the lower part of its dip-pipe would still remain sealed. It has been objected that, where an exhauster is used, there is a risk of drawing in the furnace gases through cracks in the retorts if the hydraulic seal is dispensed with, but it is always easy to adjust the pressure in the retorts to the draught in the furnaces, and if a small amount of air should be drawn in, this would be more than compensated for by the saving of gas which, with a pressure of $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in the retorts, would continually escape through the same cracks if the hydraulic seal is maintained. If, however, it is considered necessary to adopt extra precautions against this, all that is needed is to use an exhaust governor, with which all variations in the hydraulic main pressure may be avoided, and by using two such governors a perfectly uniform pressure may be maintained, and all risk of drawing in the furnace gases may be avoided.

C. G.

The Railways of the World. By ERNST KOHL.

(Der Civilingenieur, 1891, p. 375.)

The available railway statistics compiled by the German Government extend to the year 1889, and the Author finds that the total mileage of the railways of the world has, during the interval from 1887 to 1889, increased by 5.26 per cent. annually. The per-centage increase was greatest in Asia and Australia, and smallest in Europe.

In Europe there are 2.3 kilometres of railway to every 100 square kilometres of area, and 6.2 kilometres for every 10,000 inhabitants. In the United States the corresponding figures are 3.3 and 39.8 kilometres. In Great Britain there are 10.2 kilometres, and in Belgium 17.5 kilometres for every 100 square kilometre area. The total length of railways in the world is estimated at 600,000 kilometres (375,000 miles), or about fifteen times the equatorial circumference of the earth. The average cost of European railways is estimated at £56,000 per mile, and the cost of all the railways in the world at £6,423,000,000 sterling.

G. K.

On the Influence of the Introduction of Wagons of Increased Capacity on the Working Expenses of the North American Railways. By O. PETRI.

(Organ für die Fortschritte des Eisenbahnwesens, 1891, p. 273.)

According to official returns the average cost of the conveyance of 1 ton of goods for a distance of 1 mile on the North American railways amounted in 1889 to 0.922 cent. In 1870 this cost amounted to about 2.5 cents.

The Author in his report neglects all other points which might influence this remarkable reduction of about 60 per cent. in less than twenty years, and confines his attention to the working expenses.

The actual sum which determines the traffic rates consists of—

1. The amount necessary to pay the requisite interest on the cost of construction;
2. The working expenses.

Whilst in the case of European railways these two amounts are taken as equal, in America the former comprises on an average 32.42 per cent., and the latter 67.58 per cent. of the total expenses. From this fact the influence which a reduction of the working expenses has on the gross outlay becomes at once apparent.

The following Table shows the extent to which the working expenses per ton per mile have been reduced on the New York Central and Hudson River Railway :—

Year.	Total Revenue.	Working Expenses.	Net Profit.
	Cents per Ton per Mile.	Cents per Ton per Mile.	Cents per Ton per Mile.
1870	1·88	1·15	0·73
1875	1·27	0·9	0·37
1880	0·87	0·54	0·33
1885	0·68	0·54	0·14
1889	0·76	0·56	0·20

The causes of this marked reduction in working expenses are—

1. The increased capacity of the wagons, and the reduction of the dead weight per ton of load ;
2. The increased weight of the trains ;
3. The increased power of the engines ;
4. Improvements in the permanent way.

In 1867 the time appeared to have been reached at which it was no longer possible to effect a reduction of the working expenses, but the introduction of steel rails has since produced a revolution in the working of railways, and lowered the cost of transit to an extraordinary extent.

As shown in the following Table the capacity of the wagons and the mean weight of the trains on the Pennsylvania Railway have steadily increased, and the working expenses have been materially reduced :—

—	1852-55	1856-60	1861-65	1866-70	1870-75	1876-88 <i>sic.</i>	1880-85	1888
Working ex- penses in cents . .	1·98	1·38	1·46	1·36	0·79	0·503	0·444	0·501
Mean weight of train .	75·4	83·2	94·3	104·4	116·8	155	196	285
Capacity of standard wagon . .	Less than 10 ton				10	12	20	30

Similar results are shown by almost all the other lines.

Detailed official returns given in the Paper show that doubling the load by running twice the number of trains would increase the working expenses by 40·1 per cent., whilst by the employment

of more capacious wagons and heavier engines the cost would be augmented by only 13·9 per cent.

On the New York Central and Hudson River line, in spite of the freights having been reduced from 0·79 cent to 0·76 cent per ton per mile, the net profit has increased from 0·20 to 0·22 cent. This result has been attained by increasing the train-loads from 205 tons to 248 tons. A long Table of statistics in the Paper demonstrates that on lines where the gradients and curves and amount of traffic warrant the employment of specially heavy trains, the cost of coals and the amount of wages have been reduced from 0·855 cent to 0·4 cent per wagon mile.

The capacity of the wagons has been increased from 10 tons in 1875 to 30 tons in 1888, the dead weight being only raised 50 per cent. The cost of a covered wagon to carry 20 tons is \$425, whilst that of a 25-ton wagon of similar construction amounts to \$450.

A very considerable saving is effected in the cost of station yards and other works by the employment of larger wagons, owing to their greater capacity per foot run. This is exemplified in the following Table :—

Class of Wagon.	Capacity in Lbs.	Capacity per Lb. per Foot Run.
Closed . .	60,000	1,600
„ . .	50,000	1,360
„ . .	40,000	1,070
„ . .	30,000	970
Open . .	60,000	1,930
„ . .	50,000	1,840
„ . .	40,000	1,280
„ . .	30,000	970

The Author considers in detail the disadvantages involved in the employment of heavier rolling stock, and proceeds to enumerate them. The only ones to be seriously considered are, however, the difficulty of utilizing the openings and shoots in the long goods sheds whose position has been determined by the shorter trucks, the greater power required to move the trucks by hand or horses, and the increased wear and tear of the permanent way.

Statistics show that for distances up to 125 miles it is, as a rule, advantageous to adopt the use of small wagons, whilst for longer journeys the employment of heavier wagons proves more economical.

The Paper is accompanied by numerous Tables and diagrams.

J. R. B.

Compound Locomotive for Fast Passenger Service.

(The Railroad Gazette, New York, 1892, p. 117.)

This article describes an eight-wheel fast passenger locomotive, of the Vaucrain type,¹ built by the Baldwin Locomotive Works, which is remarkable as being the first really fast compound locomotive built in the United States. It is employed on the Jersey City and Philadelphia service, and the distance between the two cities is 90 miles, which is scheduled at two hours fifteen minutes, including nine stoppages, with trains of from four to nine cars. The maximum speed is 1 mile in forty seconds, and, for the higher speeds it is found to be advantageous to cut off steam late in the high-pressure cylinder, and to regulate by the throttle lever, as, under such conditions, the exhaust from the low-pressure cylinder is found to be freer. The link-motion quadrants have no notches for any earlier cut-off than half-stroke. The coal consumption per mile at an average running speed of 60 miles per hour, is estimated at 66 lbs., or 0.15 lb. per ton-mile, as based upon a recent run. The steam-pressure is 180 lbs. per square inch, and the following are the leading dimensions of this engine, which is considered to prove the merits of the Vaucrain type of compound engine for fast passenger service:—

Cylinders	{ Diameter, high-pressure	1 foot 1 inch.
	" low-pressure	1 " 10 inches.
	Stroke	2 feet.
Diameter of driving wheels	6 " 6 inches.	
" coupled trailing wheels	6 " 6 " "	
Total wheel base	22 " 3½ "	
Driving-wheel base	7 " 6 "	
Weight in working order	123,800 lbs.	
" on driving wheels	88,400 "	
Boiler, diameter	4 feet 10 inches.	
" length of tubes	11 " 10 "	
" diameter of tubes	2 inches.	
" number "	250.	
Firebox, length	10 feet 11½ inches.	
" width	3 " 6½ "	
" front depth	5 " 5 "	
" rear "	4 " 7½ "	
Truck, diameter of wheels	3 "	
" journals	5½ inches × 8 inches.	
Driving-wheel axles	8 " × 12 "	
" tyre thickness	3 inches.	
Tank, water capacity	2,916 gallons (Imperial).	

The engine is generally of the standard four-coupled "American" type with radial fire-box staying, with four-wheeled bogey truck leading.

W. H. B.

¹ In the Vaucrain compound locomotive the high-pressure cylinders are above the low-pressure cylinders, and one crosshead serves for the two piston-rods. See Minutes of Proceedings Inst. C.E., vol. cvi. p. 388.

American Car-Wheels. By S. PORCHER.

(Proceedings of the New York Railroad Club, February 1891.)

Mr. Porcher in his Paper discusses the question of "the best diameter for car-wheels." It is known that cast-iron is not as strong as wrought-iron or steel, and that the difficulty of making a perfect casting increases with the diameter. The comparative cheapness of cast-iron recommends it as very desirable for freight service. Steel is coming more and more into favour, in view of its great strength and safety. Heavy loads are carried, and there is a growing tendency to increase them; and it is specially desirable to have strong and small wheels to avoid bent axles and broken flanges. In Mr. Porcher's opinion, wheels should not exceed 33 inches in diameter for use under freight cars.

In passenger service it has been proved that cast-iron wheels larger than 33 inches do not make a greater mileage run than the 33-inch wheels, whilst they cost more per 1,000-mile run; and that cast-iron wheels smaller than 33 inches, though sometimes costing less per 1,000-mile run, are more troublesome in the end. It is thus made apparent that 33 inches is the best diameter for the wheels to be used in freight service.

For passenger service no one universal diameter can be recommended for car-wheels. 36 inches seems to be the maximum satisfactory diameter for cast-iron wheels. The 36-inch cast-iron wheel rolls well, and gives immunity from hot boxes—a fruitful source of annoyance in sandy districts. Mr. Porcher believes that for all passenger service 36 inches is the best diameter for cast-iron wheels. With regard to steel wheels, it is argued that by increasing the diameter of a wheel its total mileage run is increased in proportion, or even in greater proportion; but the wheel weighs more and is more costly, more work is consumed in starting and stopping and in lifting the large wheel over the hills. The subject of dead weight of wheel is worthy of special attention with a view to minimising it. Six pairs of 42-inch wheels and axles alone weigh from 15,000 lbs. to 16,000 lbs.

With regard to the application of brakes, it is necessary to limit the size of the wheels to such as admits of providing efficient brakes on all the wheels that carry considerable weight. This is not easily done with 42-inch wheels in a six-wheeled truck. The Pullman Company, having recognised the difficulty, is replacing its 42-inch wheels with wheels of 38 inches in diameter.

D. K. C.

Trials of Westinghouse and New York Air-Brakes.

(The Railroad Gazette, New York, 1892, pp. 113, 122.)

Trials of the above two brakes were carried out on the 3rd, 4th and 5th of February, 1892, upon the same track as the "Burlington" brake tests of 1886-7. They were made under the supervision of Mr. Rhodes, Superintendent of Motive Power of the Chicago, Burlington, and Quincy Railroad. The following brakes were tested:—

(a) No. 2 Triple-Valve, New York Air-Brake Company, on Westinghouse cylinders and reservoirs.

(b) New Westinghouse triple-valve, with No. 15 B.W.G. brass graduation springs.

(c) New Westinghouse triple-valve, with No. 13 B.W.G. brass graduation springs, taken from valves that had been two years in use on palace stock cars.

(d) Old Westinghouse triple-valves, with No. 13 B.W.G. brass graduation springs, taken from palace stock cars, which had been in use for two years.

All the triple-valves were tested without cleaning or repairs, just as they were taken from service. The cars used were 34-foot palace stock cars, which had been overhauled two years ago and fitted with Janney couplers, metal brake-beams, and quick-acting Westinghouse brakes.

The following series of stops were made with each brake and 50-car trains:—Stops 1 and 2 on a level; stops 3 and 4 on a down-grade of 53 feet per mile. The tests were made to determine the following points:—(1) Quickness of commencement of application on the last car of a 50-car train; (2) Rapidity of full application on last car of a 50-car train; (3) Distance run after brakes are applied; (4) Shocks produced in rear car at 20, 30, and 40 miles per hour; (5) Time elapsing between movement of driver's handle and shock in rear car; (6) Pressure in air-cylinders at the instant of shock in rear car; (7) Graduation test to determine if brakes would hold a partially-constant pressure in the cylinder for grade work; (8) Release test to determine if brake-shoes would come quickly off the wheels, so as to prevent delays with long freight-trains, where brakes have to be pumped off and the excess pressure used for release does not reach throughout the length of the train, or for other reasons is not available; (9) Single-car tests to determine if the triple-valves would give the emergency action when the air is rapidly discharged through the service application port of the driver's handle.

The following are the general results of the tests with the two types of brakes:—

TEST (1).

(a)	3 seconds.	(c)	3½ seconds.
(b)	3 "	(d)	3½ "

TEST (2).

(a)	50 lbs. in 4½ seconds,	70 lbs. in train pipe.
(b)	58 " 4 " "	70 " " "
(c)	59 " 4 " "	70 " " "
(d)	55 " 4 " "	66 " " "

TEST (3).

The conditions are too complex and varied to permit of a reliable comparison.

TEST (4).

Record of "Slidometer" Instrument in Rear Car,

15 to 26 miles per hour.

(a)	. . . 6.8 inches, average	(c)	. . . 0.35 inch, average.
(b)	. . . 0.05 " "	(d)	. . . 0.35 " "

30 to 33.5 miles per hour.

(a)	 3.4 inches.	(c)	 0.4 inch, average.
(b)	 0.2 " "	(d)	 0.3 inch.

36 miles per hour.

(a)		No shock.
(b)		0.05 inch.
(c)		No test made at this speed.
(d)		" " " "

The negative shocks or recoil are not considered, nor are the shocks in the front car, as they were all produced by the breaking in two of the train, and it is not clear how they result, if they do, from a difference in rapidity of brake-action.

TEST (5).

(a)	 5.5 seconds.	(c)	 6.0 seconds.
(b)	 6.4 " "	(d)	 6.2 " "

Probably the delay in the shock in the last three brakes, averaging 0.7 of a second, was due to the more rapid application of the full pressure in the cylinders. In these tests, as in those of 1886 and 1887, the greater shocks occurred at the lower speeds, owing, probably, to the greater shoe-friction at those speeds acting more powerfully on the forward part of the train before the brake applied in the rear.

Test (6). The pressure in every case at the time of the shock was, practically, that of full equalisation or maximum pressure, but the records are open to doubt.

Test (7). There was no material difference between the brakes
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tested. The tests were made with trains of twenty-six cars standing still, the reduction of pressure in the train-pipe being made at one-minute intervals. Gauges were attached to the train-pipe and auxiliary reservoir of the dynamometer car, middle car, and twenty-sixth car.

Test (8). (a) Released in ninety seconds, and sixteen cars remained braked, and were released by brakemen after a period of seven minutes. (b) All released in sixty-five seconds. Time varied from thirteen to sixty-five seconds. (c) Not tested. (d) All released in eighty-two seconds. Time varied from ten to eighty-two seconds.

These tests were made with twenty-five cars standing still; 70 lbs. train-pipe pressure being first obtained, the driver's valve was then placed at lap, and 100 lbs. pressure accumulated in the main reservoir, and full emergency application was made without letting all the air out of the train-pipe.

The handle was again placed at lap after an interval of fifteen to twenty seconds, for equalization of pressure between cylinders and auxiliary reservoirs. A signal was then given by the whistle and the driver's handle put to the running position, and the time noted by observers along the train which elapsed before the brakes released. It was claimed for brake (a) that the triple-valves had been hurriedly made, or the results would have been better.

Test (9). From this test it appeared that when there were only one or two cars in a train, the emergency action might be obtained when not wanted. Brake (a) acted thus on one occasion but not on another, and there was no emergency action with the Westinghouse light spring; but, with only two cars in a train, there would be no excuse for a driver who opened and held wide the service-port, and, even if obtained, an emergency application in such a case could do no harm.

In seven out of the seventeen stops made, the train broke in two parts, by failure of draft-rigging, drawheads, or knuckles.

Detailed records of the tests, from which the averages, above given, are deduced, accompany the description.

W. H. B.

The Boisson Metallic Coupling for Air-Brakes.

By A. DORMOY.

(Le Génie Civil, vol. xx., 1892, p. 228. 4 Figs.)

The Author remarks that up to the present time the ordinary couplings for compressed-air brakes have been made of india-rubber hose, and that, although these couplings afford perfect flexibility, yet, owing to deterioration of the india-rubber, they are frequently injured while the train is running. In order to avoid the serious results which might follow from the burst-

ing of an india-rubber hose, Mr. Boisson has brought out an improved metallic coupling. The mains are carried under the carriage frames in the ordinary manner, and a stop-cock is fitted at each end of the carriage. Above the stop-cock a special joint is fixed consisting of three articulations enabling it to rotate in a vertical and horizontal plane, and allowing the tube, which is attached to the coupling itself, to rotate also. Each articulation consists of a kind of union which enters a casting. The first union is attached to the main train-pipe, and is held in position by a nut; the other two unions are held in position by an L-shaped bolt, and each joint is kept tight by means of an india-rubber ring, double cone shaped on the outside. The true coupling consists of a similar articulation attached to the end of a straight metal pipe connected to the joint previously described: two handles are so arranged that the separate halves of the latter coupling can be brought into close contact, and a spiral spring is provided in each half of the joint, giving the requisite flexibility to the junction. The air-pressure inside the pipe retains the india-rubber rings in their position in an expanded condition. The figures in the article represent several adaptations of the invention, and the portions of the apparatus which come in contact with the india-rubber are tinned. The Author believes that the adoption of the invention would save many delays which are caused by broken connections.

E. R. D.

On Calculating Helical Springs. By A. L. DE LEEUW.

(The Railroad Gazette, New York, 1892, p. 43.)

The customary formulas for helical springs are:—

$$P = \frac{S \pi}{16} \times \frac{D^3}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

$$\text{and} \quad F = \frac{32}{\pi} \times \frac{P R L}{G D^4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2),$$

in which—

P = maximum load;

S = stress;

D = diameter of wire;

R = radius C to C of coil;

F = total deflection of coil from free state to solid compression;

L = length of wire in coil;

G = $\frac{2}{3}$ modulus of elasticity;

H = solid height, and P₁ the load at a certain height greater than H.

This formula would be undoubtedly true if coal was actually a mixture of carbon, gaseous hydrogen, sulphur, and water; but it is not actually so, the ultimate composition being no indication of the combustion existing in the fuel. In any case, it is abundantly certain that the carbon is not to any great extent present in the free state.

Later observers have found reason to question Dulong's method, and Scheurer Kestner obtained from 10 to 17 per cent. higher results or even more than that indicated by the principles of thermochemistry as obtainable from the combustion of the constituents. Such a result is, however, not impossible, but it involves the supposition that the formation of coal is attended with a negative development, or absorption, of heat. Such compounds are not unknown even among those of simpler constitution, bisulphide of carbon being an example. This develops by combustion 3,792 calories, while its constituents, 0.1579 carbon and 0.8491 sulphur, taken separately, give 1,275.8 and 1,887.2 calories, or together 3,163 calories, or a difference of about 16 per cent.

The older form of calorimeters are very delicate pieces of apparatus, in which the sample experimented on varies from about 0.3 to at most 1 gram; so that the most accurate care is required in order to obtain trustworthy results. This difficulty has been met by the establishment at the experimental station at Munich of a calorimeter of sufficient size to allow the use of several cwt. of fuel in one test. It has a combustion chamber surrounded with water, and the gases are carried through a series of cooling tubes, until their temperature is reduced to that of the surrounding atmosphere. This gives very concordant results; for instance, four successive trials of the same coal gave, 7,984, 7,887, 7,885 and 7,969, or a mean of 7,931 calories, which is sufficiently exact for practical purposes. In like manner trials with very pure charcoal gave very nearly the same figures as those obtained with the most carefully-conducted experiments from the best calorimeters.

The conclusion from a great number of different coals tried in the large experiments is that Dulong's formula is practically exact, the variations from the calculated and observed results being at most 2 or 3 per cent., and in a majority of instances about 1 per cent.

The average calorific value of pure coal, i.e., considered free from ash and water, is about 8,000 calories.

The loss of heat by evaporation of contained water, and by the heated ashes falling from the grate, is comparatively small. A coal containing a per cent. of pure coal (free from ash and water), b per cent. of ashes falling out at t_1° temperature, and c per cent. of water leaving the fireplace, as steam at temperature t_2° , develops per 100 kilograms:—

$$8,000 a - 0.2 (b t_1^\circ) - [620 + 0.4750 (t_2^\circ - 100)] c \text{ calories, or for } a = 80, b = 15, c = 5, t_1^\circ = 700^\circ \text{ and } t_2^\circ = 250^\circ \\ (640,000 - 2,100 - 3,456) \text{ calories.}$$

The losses from these sources is therefore less than 1 per cent. of the total available quantity of heat.

The most considerable item of loss in heat is that carried off by the gases, which depends upon their composition and temperature. If pure coal is mixed with air in quality sufficient to give a gas with 21 per cent. of carbon dioxide, 1 kilogram requires 2.66 kilograms of oxygen, giving 3.666 kilograms or 1.865 cubic metre of carbon dioxide, which in the chimney gases will be associated with 8.798 kilograms, or 701.5 cubic metres of nitrogen. The heating of these gases to t° Centigrade requires $(3.66, 0.2164 + 8.798, 0.244) t = 2.93 t$ calories.

If the gases contain a per cent. less carbon dioxide than 21 per cent., unburnt air is drawn over the quantity of which x per 100 of coal is, when

$$a : \left(100 - a \frac{100}{21} \right) = 186.5 : x.$$

$$\begin{aligned} x &= \left(\frac{18,650}{a} - 888.1 \right) \text{ cubic metres} \\ &= \left(\frac{18,650}{a} - 881.1 \right) \cdot 1.2937 \text{ kilograms.} \end{aligned}$$

To heat this to t° requires

$$\left(\frac{18,650}{a} - 888.1 \right) 1.2937 \cdot 0.2377 \text{ calories,}$$

and the total heat carried off in the gases is—

$$\begin{aligned} 293 t + \left(\frac{18,650}{a} - 888.1 \right) 1.2937 \cdot 0.2377 t \\ = \left(20 + \frac{5,721}{a} \right) t \text{ calories.} \end{aligned}$$

From the above formula the following Table has been calculated, showing by how much per cent. the heating effect of the coal is diminished per 100° of temperature in the gases, when the proportion of carbon dioxide in the gases is reduced below the theoretical maximum of 21 per cent:—

CO ₂ in Gases.	Heat Reduction.	CO ₂ in Gases.	Heat Reduction.	CO ₂ in Gases.	Heat Reduction.
Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	71.76	6	12.16	11	6.75
2	36.00	7	10.46	12	6.17
3	24.09	8	9.19	13	5.75
4	18.12	9	8.20	14	5.35
5	14.55	10	7.40	15	5.01

With the help of these figures it is easy to calculate what quantity of heat is required in the daily working any industrial heating arrangement.

An interesting branch of the inquiry is the comparison of these figures with those obtained from the thermo-chemical data corresponding to the reactions going on in the furnace, an example of which is given in the production of salt cake or sodium sulphate from salt and sulphuric acid in alkali, making as follows :—

a. Chemical reactions :—

$2\text{NaCl} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{HCl}$, this requires per
equivalent 142 kilograms, 15,710 calories, or per
100 kilograms 11,050 calories.
Separation of sulphuric acid from diluting water . . . 14,000

b. Alteration of state of aggregation :—

Evaporation of 20 kilograms of water . . $20 \times 520 = 10,400$

c. Heating of final products :—

100 kilograms of sodium sulphate } to 500°	$500 \times 100 \times 0.232 = 11,600$
50 kilograms of hydrochloric acid } to 400°	$400 \times 50 \times 0.1832 = 3,704$
20 kilograms of water vapour to } 400°	$400 \times 20 \times 0.475 = 3,800$
350 kilograms of air to 400° . .	$400 \times 350 \times 0.2377 = 33,278$
Total	<u>87,832</u>

In a similar manner the heat requirements for the following chemical operations have been computed :—

	Calories.
Conversion of 100 kilograms of crystallized magnesium chloride into magnesia, hydrochloric acid, and water . .	116,020
Conversion of 100 kilograms of salt cake into black ash with coal and limestone	194,453
Production of 100 kilograms of lime from limestone . . .	87,795
Conversion of 100 kilograms of water into steam at 5 atmospheres	62,665
Conversion of 100 kilograms of zinc blende into zinc oxide . .	— 52,505

The last of these operations is therefore attended with a development of heat.

Taking into account the temperature and proportion of carbon dioxide in the gases, the effect obtained from the combustion of 100 kilograms of coal in the furnaces used in these operations may be determined for comparison with that actually obtained in practice, as seen in the following Table :—

Furnace.	Working Value of 100 kilograms of coal in calories.	Coal required per 100 kilograms of Product.		Difference.
		By Thermo-Chemical Calculation.	In actual Practice.	
		Kilograms.	Kilograms.	
Steam-boiler . . .	{500,000}	{12·5}	12-15	0·5-2·5
	{550,000}	{11·4}		
Lime-kiln	{450,000}	{19·1}	18-30-43	27-11-24
	{575,000}	{15·3}		
Salt-cake furnace .	450,000	19·1	35	16
Magnesia furnace .	450,000	25·8	90-100	64-74
Black-ash furnace .	350,000	35·6	60	24·4
Zinc-blende calciner	350,000	-8·2	18	26

Apart from conduction and small uncalculated losses, the greater part of these differences must be attributed to heat dispersed by radiation from the furnace. The importance of this factor for the different kinds of furnaces is computed as follows:—

Furnace.	Daily Charge or Yield.	Daily Consumption of Coal in Kilograms.			Radiating Surface of Furnace.	Daily Radiation per Square Metre in Kilogram of Coal.
		Actual.	Computed.	Difference.		
					Sq. Metrs.	
Salt-cake	{ 3,500 kilograms sulphate }	1,225	668	557	80	6·9
Magnesia	1,120 MgCl ₂	1,060	289	771	80	9·6
Black ash	5,400 Na ₂ SO ₄	3,240 ¹	1,922	1,318	80	16·5
Blende-calciner . . .	7,000 ZnO	1,260	-574	1,834	120	15·3
Steam-boiler, 8·3 fold evaporation	62,500 H ₂ O	7,500	7,125	375	245	1·5
Steam-boiler, 6·6 fold evaporation	50,000 H ₂ O	7,500	6,250	1,250	245	5·1
Lime-kiln, iron jacketed with gas firing . . .	4,000 CaO	1,736	788	948	210	5·0
Lime-kiln with short flue producer	3,700 CaO	1,160	729	431	100	4·3
Lime-kiln, Dietzsch's form	20,000 CaO	4,500	3,060	1,440	550	2·5

¹ 60 per cent. of charge, 42 per cent. of which is burnt, and 18 per cent. mixed for reducing.

H. B.

New Researches on the Calorific Value of Coal determined by a Berthelot Calorimeter.

By Messrs. SCHEURER-KESTNER and MEUNIER-DOLLFUS.

(Bulletin de la Société Industrielle de Mulhouse, 1891, p. 577.)

The Authors of this Paper were desirous of verifying the determinations of the heating value of coal, made by them some years ago with their old Fabre and Silbermann calorimeter. With this view they obtained the loan of Mr. Berthelot's new calorimeter, a detailed drawing of which is given in the original Paper. The apparatus is very complete, and consists of a small cylindrical shell about $2\frac{1}{2}$ inches internal diameter, and $4\frac{1}{4}$ inches deep inside, with a flat cover screwed on. It is made of steel, and lined with platinum to protect the shell from the acids generated by combustion. In the centre is fixed a perforated platinum plate, upon which the coal to be tested is placed. The special feature of the instrument is that, after the coal has been introduced and the cover screwed on, pure oxygen is admitted through an opening, at a pressure of 25 atmospheres. The bomb thus charged is placed in the calorimetric vessel, containing two litres of water, and as soon as the whole apparatus has attained an equal temperature, the oxygen charge is fired by an electric spark.

This calorimeter possesses many advantages over the Fabre and Silbermann instrument. Combustion is sudden and complete, there is no unburnt residuum, and no corrections in the calculations are necessary. All the arrangements and multiplied observations required in the old system are dispensed with, and the apparatus is so simple that one operator only is needed to work it. On the other hand, it is rather costly, and the ashes cannot be weighed, because the charge ignites with such force that they are driven against the sides of the shell, and it is impossible to collect them afterwards intact. In making experiments, therefore, the Authors were careful to determine the percentage of ash beforehand in a preliminary trial. The coal to be tested for ash was ground to powder, thoroughly mixed, and made into pellets each 1 gram in weight. The proportion of ash was determined from the mean of five of these pellets burnt in the calorimeter. Another difficulty was found in estimating the calorific value of the coal. Small quantities of nitric and sulphuric acid were formed during combustion, and the heat required for these processes had to be determined and deducted from the total heat developed.

The Authors are, nevertheless, of opinion, that with this apparatus of Mr. Berthelot greater accuracy is possible than with the Fabre and Silbermann calorimeter, because it is more easily handled, and the figures require fewer corrections. As their first experiments with the Berthelot calorimeter gave slightly lower results than those of former trials, they determined to check the

new figures with a calorimeter of the old type, modified in a few important particulars. Instead of using one general coefficient of correction for the temperature of the surrounding atmosphere, the coefficient was determined separately for each trial. It was found that the Fabre and Silbermann instrument had given rather higher results than those now obtained, and that the coefficient for temperature ought to be halved.

Another important alteration was made in the method of preparing the fuel for combustion. In order to obtain perfect uniformity in the samples, it had been previously considered necessary to reduce a quantity of the coal to powder, and mix it thoroughly before burning. The Authors are now of opinion that the coal, if taken from the same pit and seam, is sufficiently regular in its structure to require no mixing, due allowance being made for the ash. In a Fabre and Silbermann calorimeter they placed a sample from the block, broken into pieces the size of a pea, and this change produced another important modification in the results. With powdered coal the oxygen used for combustion had to be mixed with air to prevent an explosion, combustion was incomplete, and unburnt gases were given off in large quantities. With lump coal pure oxygen might be used, better combustion was obtained, and the corrections for unburnt residuum were half what they had formerly been. These improvements in the old system brought the results much nearer those arrived at with Mr. Berthelot's new calorimeter.

With both calorimeters the Authors found that the calorific value of the coal was less than had formerly been calculated, although the relative heating value of the different kinds of coal was not altered. As regards their calorific value for steam-boilers, the old results were not materially affected, but the theoretic classification of coals according to the greater number of thermal units found with the calorimeter than by calculation was modified. Fewer coals showed this excess of actual over theoretic value, and more gave figures denoting a lower heating value with the calorimeter than by calculation from the elements.

Applying these new working methods the Authors proceeded to revise their determinations of the calorific value of different coals tested with the old instrument. Thus, in experiments made in 1888 with Fabre and Silbermann's calorimeter, on a sample of Nixon's navigation-coal, supplied by Mr. B. Donkin, jun., the calorific value, pure and dry, was found to be 15,955 thermal units. When burned in the Berthelot calorimeter it gave 15,660 thermal units. A sample of 1 gram Ronchamp coal tested in the Berthelot calorimeter contained 88.08 per cent. of carbon, and its heating value pure and dry was 15,516 thermal units. Experiments made on the same coal in 1868 under the old system gave the calorific value as 16,103 thermal units, or nearly 4 per cent. more.

Three samples of Welsh coal tested in the Berthelot calorimeter gave 15,654, 14,875, 15,660 thermal units as their calorific value. These figures were higher than the thermal units found by calcu-

lation according to Dulong's formula, and with one exception lower than those calculated from the heating value of the carbon and hydrogen present. In the tested sample of Nixon's navigation-coal, the heating value, as determined by the calorimeter was 115 thermal units less than that of the carbon and hydrogen combined, and 360 thermal units above that calculated from Dulong's formula. Two samples of coal from the north of France gave the following curious results. In the first the calorific value determined in the Berthelot calorimeter was 14,954 thermal units, or 0.6 per cent. more heat than the total heat calculated from the hydrogen and carbon it contained, and 4.9 per cent. more than the calorific value of the coal calculated from Dulong's formula. The other sample was found to contain 15,955 thermal units, or 6.4 per cent. less than the calorific value of the carbon and hydrogen combined, and 6.1 per cent. less than that calculated by Dulong's rule.

The Authors arrive at the conclusion that it is impossible to ascertain correctly the calorific value of any given coal by calculation, and that it should be tested in a good calorimeter. With some coals the calorific value in the calorimeter is greater than that of the combined carbon and hydrogen; with others it is less, but exceeds the calorific value calculated according to Dulong's law; while with a third kind of coal, the heat values given in the calorimeter are lower than those obtained by calculation from Dulong's rule.

B. D.

Practical Determination of the Calorific Value of Combustibles.

By P. MAHLER.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1891, p. 704.)

In 1891 the Société d'Encouragement pour l'Industrie Nationale voted a sum to defray the cost of scientific experiments upon the calorific value of coal, anthracite, coke, petroleum oil, and other combustibles. The execution of the task was entrusted to Mr. Mahler, who gives in this Paper a report on the results of fuel tests made with a Berthelot calorimeter.

The determination of the heating-value of coal and other combustibles is of great practical importance in modern industrial work. One method adopted is to obtain the total number of the heat units contained in the fuel from an analysis of its chemical constituents; but this is rather a tedious and expensive process, involving delicate laboratory work. Of the various calorimeters based on the principle of ascertaining the heating-value by direct combustion of the fuel in oxygen gas, the most efficient at present is Mr. Berthelot's.¹ The results yielded by this apparatus are

¹ *Ante*, p. 457.

extremely accurate, but it is too expensive for ordinary commercial purposes, on account of the large quantity of platinum used in its construction. Mr. Mahler's calorimeter is a modification of Mr. Berthelot's, in which platinum has to a great extent been replaced by enamel. It was the intention of the Author to furnish those practically interested in testing the heating-value of fuel with a simple and comparatively cheap instrument. Notwithstanding its low price, the details of construction are carefully finished, and the results obtained are not inferior in accuracy to those yielded by more elaborate calorimeters.

The principle governing the Berthelot calorimeter in the determination of the calorific value of fuel is the direct combustion of the substance tested, in pure compressed oxygen. A minute quantity of the fuel is introduced into a shell or hollow cylindrical vessel, enclosed in another containing water at a known temperature. The shell being hermetically closed, pure oxygen, at a pressure of several atmospheres, is admitted, and the fuel fired by an electric spark, when the presence of the compressed oxygen causes complete and almost instantaneous combustion. The heat generated is transmitted to the water surrounding the shell, the temperature of which rises immediately. The operation is so rapid that practically accurate results are obtained, without the necessity of applying the various corrections required in the older types of calorimeter.

In its main features Mr. Mahler's instrument reproduces the Berthelot calorimeter, differing from it only in size, and in material used. A drawing is given in the original Paper. The apparatus consists of an inner calorimetric shell enclosed in two vessels, one within the other, both containing water. The outer reservoir is completely filled, and is intended to protect the calorimeter inside from the fluctuations of temperature of the surrounding atmosphere. The inner vessel is closed by a carefully-fitted cover, and the temperature of the water it contains, read off on a thermometer, determines the heat generated by the combustion of the fuel. An electric spark for firing the charge of fuel and oxygen is obtained from a small battery. The oxygen is supplied at any desired pressure from a closed tube or receiver. For burning with solid fuel it is usually introduced into the calorimeter at a pressure of 25 atmospheres.

The shell itself is made of soft steel, nickel-plated on the outside. The interior is lined with enamel to protect it from the corrosive action of the nitric acid formed during combustion. The substitution of enamel for the platinum used in the Berthelot calorimeter is an important innovation in this instrument, and greatly diminishes the cost of manufacture. The shell is cylindrical in shape, tapering slightly towards the top. It is $5\frac{1}{4}$ inches in height, and weighs 4,000 grams; the maximum diameter is $3\frac{1}{4}$ inches, minimum diameter at the top $1\frac{3}{4}$ inches. The sides are $\frac{3}{8}$ ths of an inch thick, and it has a capacity of 40 cubic inches. Thus it is larger than the calorimetric shell used by Mr. Berthelot;

but Mr. Mahler, although he burns a charge of coal of the same weight, prefers a vessel of greater dimensions. Better combustion, he thinks, is thereby obtained, especially where cheap or producer-gas is tested, which often contains 70 per cent. of inert gases. Attached to the interior of the movable cover of the calorimetric shell are two platinum rods. One terminates in a flat plate, on which the minute portion of fuel to be burnt is placed; through the other the electric wire passes, conveying the current to fire the charge. The combustible having been carefully weighed is laid on the plate, the cover with the platinum rods is lowered and tightly screwed down. The oxygen is then introduced through a cock in the cover, the current switched on, and combustion instantly takes place. To keep the water in the inner vessel at an even temperature, it is gently stirred during combustion by agitators worked from levers above. The temperature is then read off by a thermometer. The rise in temperature of the water varies from 2.75° to 3.20° Centigrade.

Mr. Mahler burns only 1 gram of combustible in an experiment. He defends his use of so minute a sample by two arguments, theoretical and practical. With his present instrument it would be difficult to increase the quantity. The thermometer is gauged to register a given difference in the heat developed by combustion; but if the portion of fuel were doubled in weight, and two grams used, the temperature of the water would rise 6° instead of 3° Centigrade. The thermometer, which is minutely subdivided to mark the smallest variation, would be too short to show the increase of temperature, and Mr. Mahler does not consider it possible to lengthen it without injuring its delicacy. Theoretically he is of opinion that no advantage would be gained by increasing the amount of fuel tested. A longer period would elapse before complete combustion was obtained, and it is precisely to the rapidity with which the charge is at present consumed that Mr. Mahler attributes the accuracy of his results. The whole operation of testing the calorific value of any fuel requires thirteen minutes. Of these, thirty seconds only are reckoned for the actual combustion of the coal, and two and a half minutes for transmitting the heat from the shell to the water. All the heat to be gauged is therefore developed in three minutes. The calorimeter has been especially constructed to obtain accurate determinations in this short time with 1 gram of combustible, and if the quantity of the test sample were increased, the instrument would not only lose in simplicity, but in precision. Mr. Mahler is confident that the simple process he employs will yield results more exact and more speedy than the chemical analysis of the constituents of the coal.

To prove these assertions he gives in his Paper the data of an experiment undertaken to determine the calorific value of one gram of Montrambert coal. The rise in temperature obtained by the combustion of this sample was 3.15° Centigrade, corresponding, after deductions for the nitric acid, &c., generated in the coal, and the combustion of the iron, to 8.373 calories, or $8,373$ calories con-

tained in 1 kilogram of the coal. The same coal, when burnt in the laboratory, showed a rise in temperature of 3.11° Centigrade. This calorimeter can also be used to determine the heating-value of liquid and gaseous fuels. When gas is tested a vacuum must be produced in the shell before the gas is admitted, and the quantity of oxygen necessary for combustion previously determined. Illuminating-gas ignites with oxygen at a pressure of 5 atmospheres, producer-gas requires a pressure of about half an atmosphere in the oxygen; but upon this head Mr. Mahler does not speak authoritatively. He is still engaged in experiments to determine the heating-value of gas, and intends to make them a special feature of this calorimeter. With the apparatus he has presented to the Société d'Encouragement, he has already made 300 tests.

In the original Paper a Table is given of experiments determining the heating-value of coal from five different districts in France, also anthracite coal from Tonkin and Pennsylvania, and heavy and refined petroleum oil from America, Baku, and the Caucasus. The results obtained with the calorimeter are also compared with those deduced from chemical analysis of the constituent elements of the fuel. A second Table shows the heat balance obtained by the distillation of Commentry coal. For the sake of comparison, Mr. Mahler gives the heat of combustion of naphthalene tested in his and in Mr. Berthelot's calorimeters. The mean of three experiments made by him was 9,688 calories, Mr. Berthelot determined the heat at 9,692 calories. This close approximation in the results establishes the identity of method employed in the two instruments.

Mr. Mahler has lately tested a sample of Nixon's navigation-coal supplied by Mr. B. Donkin, jun.

B. D.

Fuel-Gas. By A. KITSON.

(Journal of the Franklin Institute, December 1891, p. 424.)

Of the three methods for converting coal into gas for fuel, namely:—By natural or forced draught without steam, by forced draught with steam, and by steam and air alternately—resulting in the generation of producer-gas, semi-water gas, and water-gas respectively—semi-water gas contains from 80 to 85 per cent. of the heating-value of coal, and is the cheapest gas if supplied within a reasonable distance from the place of production.

Producer-gas must be burnt hot as it issues from the producer to be advantageous. Water-gas contains only about two-fifths of the heating-value of the coal from which it is produced, and is, in itself, the most expensive of the three systems. Not the least of the advantages which semi-water gas or "steam-jet" producer-gas, as it is sometimes called, possesses over water or coal is the

ease and simplicity of its production. Its production is automatic, and it can be made in quantities varying from 500 cubic feet upwards per hour. The Paper contains detailed calculations of heat produced and heat expended on the three systems.

Mr. Kitson has designed a producer of semi-water gas now in use in the Körting gas-engine for the production of power. The engine supplies power to a dynamo. The battery furnishes current for a number of glow-lamps, and occasionally for a small electric motor. The producer consists essentially of a cylindrical shell of boiler-plate lined with fire-brick. The internal diameter of the brickwork is 21 inches, and the height from the grate to the top of the furnace is $3\frac{1}{2}$ feet. The grate is connected at one side with a steam and air injector, and on the other side with a gas-supply pipe. It is surrounded by a cast-iron ashpit. A small reservoir or boiler is placed at one side, connected with which are two coils contained in the brickwork, the lower of which supplies steam, and the upper one of which superheats it. Air-channels are formed in the brickwork, arranged spirally, through which air is drawn by the injector and heated before mixing with the steam. The grate is provided with mechanism, giving it a rotary and up-and-down movement to break up clinker or caking soft coal. Five hundred cubic feet of gas per hour can be produced from 6 lbs. or 7 lbs. of coal.

As a general result of experimental tests of semi-water gas with Körting gas-engines of from 2 HP. to 18 HP., with a consumption of 85 cubic feet, 1 actual HP. by break test is developed, equivalent to $1\frac{1}{4}$ lb. of coal per HP. per hour. The Author is of opinion that the gas-producer and gas-engine must eventually supplant steam for at least small uses. He deduces from his experiments:—(1) That it is decidedly advantageous to clear the cylinder entirely of the exploded products before taking in a fresh charge; (2) That a higher degree of compression than that ordinarily used with illuminating-gas is beneficial; (3) That sufficient time should be allowed to enable the gas and air to intermingle in the exact proportions for combustion before ignition.

D. K. C.

On the Characteristic Equation for Steam. By C. ANTOINE.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxiv., 1892, p. 162.)

Using some values of the temperature, density, and pressure of saturated steam given by Hirn, the Author finds that the following relation is very approximate:—

$$\frac{w(t + 438)}{P} = 31.35;$$

where w is the weight in kilograms of a cubic metre of saturated

steam at the temperature t° Centigrade, and at the pressure P in metres height of water column. But if V is the volume of a kilogram of saturated steam in cubic metres—

$$31.35 P V = t + 438.$$

The total heat of saturated steam is—

$$H = 606.5 + 0.305 t.$$

Eliminating t ,

$$P V = 0.105 (H - 473).$$

Extending this relation to steam superheated from a saturation-temperature, θ to a temperature t , the Author assumes—

$$H = 606.5 + 0.305 \theta + 0.48 (t - \theta)$$

and obtains—

$$w = \frac{19.9 P}{278 - 0.365 \theta + t}$$

W. C. U.

Experiments on the Overheating of Steam-Boilers.

By J. HIRSCH.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1890, p. 302.)

The Author relates the results of various experiments undertaken to determine the cause of overheating in boilers. A boiler is said to have been overheated when the boiler-plate has become red-hot at any given spot, and the phenomenon is recognized by the bluish shade the iron assumes when cold, due to the formation of a layer of oxide. Overheating alters the quality of the metal, and disintegrates the joints, and unless at once detected and remedied, it ultimately results in an explosion. Hence it is the source of much anxiety, and various attempts have been made to account for it. The reason generally assigned, an insufficient supply of feed-water, cannot be accepted as a full explanation, for cases have occurred in which a boiler has become overheated when full of water. It was to contribute to the solution of this intricate, but most important question, that the Author made the experiments here recorded.

The fundamental principle on which a boiler is constructed is to serve as a vehicle for the transmission of heat. Overheating differs in its intensity, but not in its nature, from the ordinary phenomena of the passage of heat through metal. In a boiler the iron plate has water on one side, and on the other the heat from the furnace, which acts upon it by radiation and contact. Before reaching the water this heat has three obstacles to surmount.

1. It enters the metal through its exterior surface, acting through what is called its external conductivity. 2. It penetrates the thickness of the boiler-plate, bringing into play its internal conductivity. 3. It passes from the interior surface of the metal to the water, acting again through the external conductivity of the metal. These three phases of the exchanges of heat between the flame and the water have already been the subject of many researches. Heat is more rapidly communicated to a fluid than to a gas. Therefore in the wall of a boiler the surface in contact with the water will have almost the same temperature, while the opposite surface will be much cooler than the gases or flames impinging on it. Heat is easily transmitted through the metal, unless there is any flaw in it, or extra thickness, as of a joint; but an incrustation or layer of grease interposed between the surface of the metal and the water, checks the natural flow of the heat, and any of these causes, by arresting the heat in its passage from the furnace to the water, may lead to overheating.

Before considering the causes of the phenomenon, the intensity of the flow of heat through the boiler-plate at its hottest part ought, if possible, to be ascertained, and it was to the elucidation of this point that the Author's first experiments were directed. He divides the subject under three heads. I. The evaporative power of a boiler in the vicinity of the part where overheating usually occurs. II. The transmission of heat through the metal, and from the metal to the boiler. III. The especial influence of a layer of grease on the heat-conductivity of the coated surface.

I. In calculating the evaporative capacity of boilers, it is usual to reckon it at so many lbs. per square foot of heating-surface. But the Author is of opinion that this method is not sufficiently accurate to determine the maximum evaporation at any given point, since evaporation is not and cannot be uniform throughout a boiler. A boiler becomes overheated at its hottest part, that is, the part subjected to the greatest heat, and the largest quantity of water will be here evaporated. To study the phenomena of overheating, the effects of heat at this particular part, and the amount of evaporation from it, must be determined. The Author, therefore, isolated a portion of a boiler-plate immediately above the bridge, where the heat is known to be greatest and overheating most frequently takes place. He placed upon it a small vertical iron tube, which was firmly bolted to the bottom of the boiler; the top of the tube rose above the level of water, and opened into the reservoir of steam. The tube was fed through a separate pipe with water at the same temperature as that in the rest of the boiler, and the quantity of water evaporated by this limited area of heating-surface was carefully measured.

The experiment was made on a cylindrical boiler, with four separate lateral feed-water heaters, of which a sketch is given in the original Paper. The boiler was 10 feet long, and 2 feet 2 inches in diameter, with a heating-surface of $35\frac{1}{2}$ square feet; heating-surface of the feed-heaters $107\frac{1}{2}$ square feet; total $142\frac{1}{2}$

square feet. The grate-surface was 3.85 square feet, and a blower increased the draught when a stronger fire was required. The small experimental tube was 4 inches diameter, with a heating-surface of 19.3 square inches, bolted to the boiler, and the joint made with asbestos and india-rubber. The tube was connected to the water-gauge of the boiler, and the same level of water maintained in both. Previous to an experiment the boiler was heated for several hours, and communication was then cut off between it and the experimental tube. During the trials the pressure in the boiler was kept at about 60 lbs. The fire was stoked as usual, the consumption of coal noted, and the total evaporative power of the boiler determined.

In the original Paper the results of the experiments are summed up in a table, showing the total consumption of coal and water, the consumption of coal per hour per square foot of heating-surface, and the corresponding evaporation of water from the boiler, the feed-water heaters, and the tube which covered the portion most liable to overheating. With different intensities of fire, the consumption of coal per hour per square foot of grate varied from 16 lbs. to 48 lbs. The Author, however, does not advocate such excessive duty, and considers that any consumption of coal above 30 lbs. per square foot of grate, represents a rate of firing inconsistent with the safety of the boiler. As a rule, with stationary boilers having the above proportions of heating to grate-surface, from 1.6 to 2.4 lbs. of water are evaporated per hour per square foot of total heating-surface. Here the maximum evaporation was 94 lbs., and the minimum 19 lbs., or from two to four times as much as in a locomotive boiler. Evaporation was extremely active from the portion of the boiler-surface covered by the tube, varying from 20 lbs. to 49 lbs. of water per hour per square foot of heating-surface with moderate firing, from 40 lbs. to 48 lbs. with strong firing. The forced draught increased combustion but not evaporation. The Author concludes that, with stationary boilers, working under ordinary conditions, evaporation at the part most exposed to overheating ought not to exceed 20 lbs. to 28 lbs. of water per square foot of heating-surface per hour, and never attains 50 lbs. in practice.

II. Having thus determined the intensity of the heat transmitted from the fire to the outer surface of the metal, the Author proceeds to examine the second branch of his subject, the propagation of the heat through the metal, and from the metal to the water. It is comparatively easy to gauge the extent of the flow of heat through a boiler-plate, but when the boiler is at work the abnormal conditions of temperature under which it is liable to become overheated cannot be studied. To realize them as far as possible, the Author was obliged to abandon the steam boiler hitherto used, and to carry out his experiments on a small apparatus specially constructed for the purpose, a drawing of which is given in the Paper. A circular piece of boiler-plate, $\frac{3}{8}$ inch thick, 15.7 inches diameter, was exposed to a strong flame on one side, and covered

with water on the other. The quantity of heat passing through the plate evaporating the water, and the temperatures of the iron on the side next the fire, were carefully measured. To generate the heat a small experimental furnace was constructed in the following manner.

The circular piece of boiler-plate was placed over a kind of crucible, lined with fireclay, with a pipe at the bottom, through which a jet of gas was fed with compressed air from a little pump like a blow-pipe. The upper edge of the crucible was about $\frac{1}{4}$ inch distant from the plate, and was encircled by a second outer casing of fireclay, which served the double purpose of concentrating the heat, and limiting the portion of the boiler-plate subject to it. The flame was allowed to play between the crucible and the bottom of the plate. To measure the heat passing from the flame through the iron plate, a small copper cylinder was placed upon and solidly jointed to the plate, the two forming a miniature experimental open boiler, in which a water-level was always maintained. The quantity of water evaporated at atmospheric pressure from this apparatus gave the measure of the quantity of heat passing through the iron plate. The top of the little boiler was surmounted by a conical cover, a small space being left between them through which the steam escaped, while the rim of the cover caught the condensed water, thus forming a kind of jacket. Distilled water was used from a large vessel, whence it passed into a glass bottle, with a scale for gauging the quantity. By this arrangement the level of water in the boiler was uniform.

The method adopted by the Author to measure approximately the temperatures of the surface of the plate exposed to the fire, is one of the most interesting features and chief points of novelty in his Paper. A certain number of metallic alloys were prepared, fusible at known temperatures. Circular recesses were drilled in the boiler-plate, over the area covered by the flame, and filled in or plugged with these alloys, carefully disposed in such a way that it might be safely assumed that the transverse section of each plug was of the same temperature as the iron surrounding it. After each experiment the bottom of the plate was examined. In a certain number of the plugged holes, the alloys, being fused at a lower temperature, would be found melted; in the others, filled with alloys melting at a higher temperature, they would be intact. The temperature of the surface of the metal must therefore, during the experiment, have been between that of two of the alloys, higher than that at which the least easily fusible plug was melted, and lower than that of the plug remaining intact at the next higher temperature.

Twelve of these plugs of alloy, carefully numbered, were arranged according to the temperatures at which they melted, in a circle of $2\frac{3}{4}$ inches diameter, round the centre of the bottom of the plate. A second series of twelve plugs was disposed outside these, round the same centre in a circle of $4\frac{3}{4}$ inches diameter, the diameter of the boiler-plate enclosed within the casing of fireclay

being $6\frac{3}{8}$ inches. The recesses filled in by the alloys were $\frac{1}{8}$ inch diameter, and $\frac{1}{4}$ inch deep, the thickness of the boiler-plate was $\frac{3}{8}$ inch. Each of the twelve plugs of alloy forming the outer or the inner circle melted at a different temperature, but one plug in each circle contained the same alloy, and therefore melted at the same temperature as the similar plug in the other circle. The corresponding plugs were placed at opposite sides of the circles, in order that any inequality in the heat of the flame at different points in the plate might be detected, by the melting of the alloy in the one plug, and the partial fusion of the same alloy in the plug of the other circle. The temperatures at which the alloys melted ranged from 230° Fahrenheit, to lead at 635° Fahrenheit, and zinc at 842° Fahrenheit. In one experiment, for instance, plug No. 7, in the inner circle containing an alloy melting at 369° Fahrenheit, was found to be slightly fused; and plug No. 8, the alloy in which melted at 428° , was intact; the temperature of the plate during the experiment was therefore between 369° and 428° , but nearest to 369° .

By this method the Author was able to determine, first the approximate temperature of the plate when strongly heated from below, and secondly, the quantity of water evaporated at that temperature. His first experiments were made with distilled water in immediate contact with the plate. The results are plotted on a diagram, the abscissæ of which represent the quantity of water at 32° Fahrenheit evaporated per hour per square foot of heating-surface, and the ordinates the temperatures of the plate. Two lines are traced on the diagram, showing the variations of temperature of the inner and outer circles of plugs, as compared with the amount of water evaporated. In an experiment made on the 23rd August, 1887, the temperature of the plate, determined from the plugs of alloy, fused and not fused, was between 338° and 369° , and 29 lbs. of water were evaporated per hour per square foot of heating-surface.

From these experiments the Author drew the following conclusions. The temperature of the surface of the plate was never uniform throughout. In the inner circle of plugs, that is, the part subject to the direct action of the flame, it was hotter than that within the outer circle, the difference being about 29° . The temperature of the surface exposed to the fire rises progressively with the increase in the quantity of heat passing through it. The point of greatest importance, however, is not the actual temperature of the metal, but the excess of this temperature above that of the water in the boiler, which latter is a constant, namely, 212° Fahrenheit. The Author takes as a basis the difference between the temperature of the plate and that of the water; such temperature difference resulting in the number of lbs. of water evaporated per square foot of heating-surface. With an evaporation of 20 lbs., this difference was 135° ; but the greater the evaporation, the greater the difference between the temperature of the plate and of the water. With 40 lbs. evaporated, it was 180° .

The Author is of opinion that if the temperature of the water rises in any boiler, the difference does not increase in proportion. Thus, if in a boiler-plate $\frac{3}{8}$ inch thick the water be at a temperature of 356° , with a mean pressure of $8\frac{1}{2}$ atmospheres, and 40 lbs. per hour per square foot be evaporated, the corresponding difference ought to be 180° , but the iron will never attain a temperature of 536° . It is well known that if a paper saucepan filled with water be held over a flame the water will boil, but the paper will not burn; but if a sheet of paper be placed between the flame and the saucepan the sheet will burn directly, while the saucepan remains intact. However great the evaporation, therefore, the Author thinks there is no danger of overheating, provided the metal be sound and in direct contact with the water.

But if the free transmission of heat be hindered in any way, either in the metal itself, or in passing from it to the water, different conditions are established, the effects of which were studied in another series of experiments. Two were made with water artificially thickened, and containing successively 0.2 per cent. and 0.5 per cent. of its weight in starch. These showed that the difference between the temperature of the surface and the quantity of water evaporated was slightly greater than when the experimental boiler contained pure distilled water, but the presence of starch in the water did not apparently tend to overheating.

In the next experiments the incrustations often found in the bottoms of boilers were imitated by covering the interior surface with a layer of plaster $\frac{1}{8}$ inch thick. To prevent the plaster cracking, the fire during the experiment was small, and the evaporation never exceeded $37\frac{1}{2}$ lbs. per hour per square foot of heating surface. The difference between the temperature of the plate and the water was found to be about 54° higher than when distilled water was in direct contact with the metal. The layer of plaster was then increased to a thickness of $\frac{3}{8}$ inch when to evaporate 30 lbs. of water, the external temperature of the iron-plate rose above 482° , and to evaporate 40 lbs. it exceeded 752° . The difference between these temperatures and those obtained when the water and the metal were in immediate contact were respectively 63° and 378° .

The next experiments were intended to show the effect on the evaporative power of the boiler of a break in the continuity of the iron by a flaw or join. In the one case the two parts of the metal are brought close together, in the other they were separated by a thin layer of foreign substance. Upon the face of the plate touching the water a sheet of steel $\frac{3}{8}$ inch thick was placed, and a piece of tin foil laid between the two surfaces. The whole was then heated, and as the tin melted, the bolts holding the surfaces together were tightened and part of the tin squeezed out. Experiments carried out with the plate under these conditions showed that the temperature line in the diagram was almost parallel to that obtained with the single boiler-plate except when the rate of evaporation was high. When 60 lbs. of water per hour per square

foot of heating surface were evaporated, the temperature of the surface of the plate exposed to the fire was 392° above that of the water, and the Author draws the conclusion that riveted boiler-plates should never be exposed to too strong a fire, even when a perfect connection has been established between them. Flaws in the metal were imitated by strewing the interior surface of the plate with finely powdered talc; the sheet of steel was then affixed and tightened on to the plate till the distance between them was only $\frac{1}{10}$ of an inch. The boiler was filled with distilled water, and with 30 lbs. evaporated per hour per square foot of heating surface the temperature of the plate exceeded 662° , being 270° in excess of that it had acquired when in direct contact with the water. With an evaporation of 50 lbs. all the plugs, even those filled with zinc, were melted; the temperature therefore exceeded 842° , and the plate was in danger of becoming overheated. This example exhibits the danger of flaws in that part of the metal nearest the fire.

A last experiment was made to show the effect of fire-brick upon the evaporative power of the boiler. The furnace was filled with small pieces of fire-brick, and the result showed that the transmission of heat to the boiler plate was not in any way effected by the presence of the bricks.

To exhibit the results of these experiments the Author shows in one diagram all the different lines of temperatures obtained under the varying conditions described. Under ordinary circumstances the evaporation from a stationary boiler does not, at the point most liable to overheating, exceed from 20 lbs. to 28 lbs. per hour per square foot of heating surface, and can never with the strongest fire reach 50 lbs. The diagrams show that with distilled water and a normal evaporation of 20 lbs. to 28 lbs., the difference between the temperature of the water and that of the external surface of the plate next the flame varies from 135° to 153° . Even with 50 lbs. evaporation it is not 198° , and dangerous differences of temperature are only possible with the abnormal evaporation of 80 lbs. to 100 lbs. The largest difference representing the greatest danger of overheating was shown to be when the boiler was covered with a layer of plaster $\frac{3}{8}$ inch thick, and when a flaw in the metal was imitated with powdered talc.

III. Under his third and last head the Author proceeds to examine the important effect upon the transmission of heat of a thin layer of greasy substance interposed between the metal and the water. He covered the interior surface of the plate with mineral oil, which was then wiped off and left a greasy layer of no appreciable thickness, but sufficient to prevent the adherence of the water to the iron. The rest of the experiment was carried out in the ordinary way, and it was found that even when the fires were kept moderate the exterior surface of the plate was at a very much higher temperature than when the water came into direct contact with it. With strong flame the experiments gave two different results. In certain cases the increase of temperature

corresponded with the increase in the intensity of the fire. The difference between the temperature of the water and of the flame surface of the plate was 90° higher than in the pure water experiments with an evaporation of 30 lbs. per hour per square foot of heating surface. With an evaporation of 50 lbs. it was 144° higher, and the temperature of the flame surface of the plate was 360° above that of the water. In the second experiment with a moderate fire and an evaporation of $34\frac{1}{2}$ lbs. all the alloys were melted, proving that the temperature of the plate had exceeded 842° . The effect of greasing the inner surface of the boiler is thus twofold; it either causes a moderate increase in the temperature of the heated surface, or with a fire of ordinary intensity the metal becomes heated to a dangerous degree.

The Author next made a new departure in his researches. In order to watch the phenomena taking place at that part of the metal where the heat passes from it to the water, he took away the small boiler on which he had hitherto carried out his experiments, and substituted for it a small tinned iron saucepan, placed on the top of the furnace in the crucible. He had observed that where an abnormal elevation of temperature was attained in the experiments, black patches, apparently arising from the partial decomposition of fatty matter, adhered to the boiler at the beginning of the trial. Wishing to discover if they had any influence on the phenomena of the transmission of heat, he greased a clean tinned saucepan with mineral lubricating-oil (*oléonaphte*), and heated it without water over a slow fire to decompose the fat. The bottom of the saucepan was found to be covered with black grease, to which water would not adhere. The saucepan filled with water was placed over the crucible, and fire applied beneath it. After boiling a minute, one part at the bottom of the saucepan was seen to become red hot, and the incandescence soon spread over the rest of the area covering the mouth of the furnace. Evidently the bottom of the saucepan was never wetted at all, and the water was in a spheroidal condition. It is a most interesting sight, the Author says, to observe the saucepan become red hot while the water is boiling above it, the tin of course being all melted. If the grease at the bottom of the saucepan is confined to one place, that part alone will become red hot at first, but the glow will soon spread over all the surface exposed to the heat. This experiment was repeated several times with flames of varying intensity. With heat corresponding to an evaporation of about 54 lbs. per hour per square foot of heating surface, the colour of the bottom was bright orange; when 30 lbs. were evaporated it was dark cherry. The phenomena differ according to the kind of greasy matter on the surface.

From various experiments of this kind the Author drew the following conclusions:—If a perfectly clean tinned iron saucepan is used, however intense the fire, the water boils in the usual way, and the tin is not melted. Nor is the surface affected by the heat when the saucepan is oxydised or covered with a thin layer of cold

mineral oil. But if the oil is previously decomposed by heat, or if a rag smeared with this oil is laid at the bottom of the saucepan, overheating immediately takes place. The same effect is produced if a solution of salt is burned in an oxydised saucepan, and the bottom, when covered with a thin crust of salt, is smeared with cold mineral oil. The smallest quantity of linseed oil at the bottom of the saucepan immediately produces overheating, even with the low evaporative power of 20 lbs. to 24 lbs. Spirits of turpentine or oil of turpentine do not cause overheating unless mixed with a minute portion of linseed oil. It is easily produced with red lead, but not so quickly with colza as with linseed oil. Valvoline when laid on cold only causes a dangerous glow when the heat is very intense, evaporating 70 lbs. Pitch at the bottom of a tinned saucepan floats off when the water boils; it adheres to an oxydised surface, but does not unduly heat the iron.

The results of these researches are summarised by the Author as follows:—

1. A sound boiler-plate, if in immediate contact with the water, does not in any part of its surface, even if exposed to a strong fire, acquire a dangerously high temperature.

2. The viscosity of the water does not prevent the boiler-plate from being wetted, nor sensibly diminish the refrigerating power of the water.

3. If the boiler-plates overlap, the transmission of heat is more or less impeded. Even a well-made joint ought not to be exposed to too fierce a fire.

4. A flaw in the thickness of a boiler-plate, or the least separation between two plates when bolted together, are almost sure, if exposed to too strong a heat, to cause injury to the boiler.

5. The contact of the flame with fire-brick is not dangerous if the boiler-plate be in one piece and well wetted.

6. Any fatty deposit on the interior surface of a boiler-plate greatly hinders the transmission of heat.

7. If the deposit is caused by a substance easily decomposed by heat, overheating is more likely to occur. Vegetable grease, therefore, as linseed or colza oil, seems in this respect much more dangerous than mineral oil.

Lastly, if a boiler be carefully fixed, kept clean, and filled with water, it runs no risk of burning even if the fire be strong. But if it is subject to great heat all precautions should be taken to eliminate everything which may hinder the transmission of heat through the thickness of the metal, or from the metal to the water.

B. D.

On the Realization of the Spheroidal Condition in Steam-Boilers.

By A. WITZ.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxiv., 1892, p. 411.)

One class of disruptive explosions of boilers under steam is generally ascribed to circumstances leading to the establishment of the water in its spheroidal condition and subsequent sudden transformation into steam at high pressure. The fact of the slow evaporation from water in that condition is shown in the results of some experiments, where the same quantity of water (1.41 oz.) was vaporized at certain fixed temperatures, and the time required was observed; the temperature given is that of the metal of the boiler, which was maintained constant in a mercury bath or by direct application of the fire.

At	°		°			Time required.	
	Centigrade.	or	Fahrenheit.			Minutes.	Seconds.
At	141	or	286	.	.	2	0
"	194	"	381	.	.	0	38
"	243	"	470	.	.	0	25
"	260	"	500	.	.	0	22
"	320	"	608	.	.	0	20
"	cherry red			.	.	10	20

Thus in the spheroidal condition the rate of vaporization was thirty-one times less than at 320° C.

A series of experiments were then made with a small upright cylindrical boiler, so constructed that the bottom was detachable, and thus any thickness of plate could be used for it. The water was maintained at some constant level, but the actual temperature of the boiler-plate was not measured, as the Author was here interested only in the question of the possible rates of vaporization with excessive firing. Detailed results of one experiment where the height of water was 3.15 inches are given below; the last

Nature of Heating.	Barometric Pressure in Inches.	Temperature of Feed-Water.		Water Evaporated per Hour.	
		° Centigrade.	° Fahrenheit.	Kilogram per Sq. Metre.	Lbs. per Sq. Foot.
Seven Bunsen burners .	29.33	15	59	63.3	13.0
" " and one air-blast	29.84	16	61	179.4	36.8
Seven Bunsen burners and one oxy-hydrogen .	29.84	18	65	200.9	41.2
Seven Bunsen burners and three blow-pipes .	29.65	19	67	263.2	54.0
Coke with air-blast . .	29.92	19	67	433.5	88.9
Seven Bunsen burners, one air-blast, and one oxy-hydrogen blow-pipe	29.70	14	57	662.8	136
Coke with air-blast . .	29.92	90	194	994.3	204

two sets of figures being obtained after the water was allowed to evaporate and the bottom plate to become red hot, and the feed water again admitted as before.

In none of the first five cases did the plate become red hot, as the surfaces in contact with the water had been carefully cleansed, but the supports of the boiler were raised to a dark red heat, and the liquid was in violent agitation. In the remaining two cases the plate remained red hot, and, in fact, in the last its glow was not deadened at all.

The Author concludes, therefore, that if the plate of a boiler becomes red hot, the water does not assume the spheroidal condition, but the rate of evaporation is increased to an excessive amount as shown in his experiments.

F. J.

Applications of Superheated Steam for Steam-Engines; Experiments made under the Direction of the Alsatian Association of Steam-Engine Proprietors.

By W. MEUNIER, Chief Engineer.

(Bulletin de la Société Industrielle de Mulhouse, 1891, p. 590.)

This Paper gives an account of a series of steam-engine experiments made in 1891 with and without superheated steam, with the view of ascertaining the actual economy of fuel and steam realized by superheating. With one exception the trials were carried out upon Woolf beam-engines. One object was to determine whether, by the use of superheated steam, sufficiently favourable results could be obtained from old and uneconomical steam motors to justify their retention, instead of discarding them for modern engines. Unfortunately the Author and his coadjutors were only able to test two kinds of superheating apparatus. Other methods were either not reduced to practical working conditions, or, like the Schwoerer system, the experiments made upon them were not ready for publication. In this Paper the results of eight sets of experiments are given, preceded by a short account of the method adopted of superheating the steam.

"Gehre" Superheater.—In this system, as at present used, the steam is not heated by a separate apparatus, but the superheating-pipes are placed in the flues of the boiler. This method of superheating the steam has been extensively adopted. It is simple, requires no separate stoker, and can be easily introduced into existing flues. One apparatus is often used to heat the steam from two boilers. Where the boilers are at a distance from the engines and long steam-pipes are required, the Gehre system has been found insufficient. The inventor is now endeavouring to remedy these defects, and to adapt his method to other working conditions.

A series of experiments extending over six days were carried

out with the Gehre superheater. The economy obtained by the use of superheated steam was calculated in quantities of coal pure and dry (deducting moisture, ash, and clinker), and care was taken to make all the trials under ordinary working conditions. Four boilers were in use, and a Green feed-water heater. There were three sets of superheaters, and the hot gases passed once only under the boiler, and then through the flues, on their way to the economiser. The steam was used by a couple of Woolf beam-engines with variable expansion, and was superheated 100° Fahrenheit. The trials were in pairs on two successive days with and without superheating, and each trial lasted about ten hours and a half. The mean pressure of steam was $5\cdot5$ atmospheres. In the original Paper Tables of results of the experiments are given in full detail, both for the boilers and the engines. The economy due to the use of superheated steam was $11\cdot2$ per cent. of steam per hour per IHP., and $8\cdot7$ per cent. of coal pure and dry per IHP. per hour. The gain per cent. was less than might have been expected, and lower than in the later trials. The defective utilization of the heat is attributed by the Author to the insufficient surface of the superheater, which was too small for the size of the boilers. The same engine had been tested a few years previously with ordinary steam. With five boilers instead of four in use, practically the same results for HP. and consumption of coal were obtained, showing that with superheating four boilers would do the work, whereas five were required with ordinary steam.

"Uhler" Superheater.—This is the first of his new appliances at work in or near Mulhausen, for superheating the steam with a separate fire. It resembles a Field boiler. The ordinary steam passes from the boilers into a series of small vertical pipes, set inside larger tubes, and heated directly from a separate furnace. The steam is thus dried and superheated, as it rises through a number of these tubes into a collector, and thence it is led in well-covered pipes to the steam-engines. This method of superheating was not found entirely successful at first, but improvements have been made, and it has now but one main defect, namely, that sedimentary deposit is sometimes formed at the bottom of the large tubes. Superheating being principally applied to high-pressure boilers, the steam contains and carries along with it a certain quantity of water, and it is liable to deposit the impurities in this water at the lower end of the tubes, over the fire. If pure water be used, the tubes are kept clean, and there is no danger of their becoming clogged. The distance from the fire to the bottom of the tube is 8 feet.

Four experiments on successive days, March 3, 4, 5 and 6, were made on the Uhler superheater. The economy obtained by superheating is given in steam per IHP. per hour. Three boilers were used with a Green feed-water heater. The superheated steam passed directly, without entering the jackets, to the valve-chests of two Woolf beam-engines, both of the same dimensions. On the first two days experiments were made with superheated steam

and on the last two days with ordinary steam. The mean pressure of the steam was 5 atmospheres, and it was superheated 133° Fahrenheit. The experiments lasted about ten hours and a half, or one working day. The economy in steam due to superheating was found to be 22·4 per cent., and the number of revolutions and the IHP. were also greater than when working with ordinary steam. The loss by radiation was small in these trials.

In the next two experiments made in March 1891, with and without superheated steam, the economy realized by the application of superheating was 30 per cent. in consumption of steam, and 27 per cent. in coal pure and dry. The steam was superheated 120° Fahrenheit, and the mean pressure was 4·7 atmospheres. The engines tested were about thirty years old, and were shortly to be replaced by new. The next two experiments, made under the same conditions, showed a slight leakage in the feed-water pipe, which affected the accuracy of the results, although the trials gave a coal economy, due to superheating, of 22 per cent.

During April and May four experiments were made on the same engines as before. Each trial consisted of an experiment one day without, and the next day with superheated steam. In all the superheating tests, the steam passed directly to the valve-chests, without entering the cylinder-jackets, and the work was done with one boiler less than with ordinary steam. The experiments in April gave 19·32 per cent. economy of steam, and 25·6 per cent. economy in coal due to superheating the steam 135° Fahrenheit, and the pressure of the steam was 5·2 atmospheres. In the May experiments, two boilers were used instead of three with ordinary steam. With steam at a pressure of 7·3 atmospheres, and superheated 93° Fahrenheit, the steam economy was 23 per cent., and coal economy 23·4 per cent. The superheater was some distance from the boilers, and this diminished the temperature of the steam although the pipes were fairly well covered. Experiments carried out on the 25th and 26th June did not yield such favourable results. The economy obtained by the use of steam at a pressure of 6·4 atmospheres, and superheated 115°, was 20·6 per cent. of steam, and 17·8 per cent. of coal; but the power was unequally divided between the two cylinders, and other working conditions were not as favourable as before.

The last series of experiments was made on two successive days in August 1891, under the same conditions on a Woolf beam-engine. The superheater was nearer the engine and boiler than on any previous occasion. Three boilers were used when the steam was superheated, but with ordinary steam four were found necessary to develop the power. The results were more favourable than in the previous experiments. An economy of 27·2 per cent. of steam superheated 113° was realized, and 25 per cent. in coal. The steam-pressure was 5 atmospheres.

From the complete details of all the tests given in the original Paper, of which the above figures are only a very brief summary, the Author draws the following conclusions:—Taking the mean

of the seven experiments made with the Uhler superheater, the increase in the boiler efficiency was 5.2 per cent., and the quantity of coal burnt per hour per unit of heating-surface, was diminished 11 per cent. with superheated steam. With this steam 20.7 per cent. less in quantity was produced per hour per unit of heating surface for same work done with the same number of boilers as under ordinary conditions. By the use of superheated steam, therefore, one boiler in four can be dispensed with; the fuel was also better utilized, and the boilers kept in better condition, because a smaller quantity of coal was burnt, and less steam evaporated per hour per unit of heating-surface. It was found, and this is an important practical result of these interesting tests, that no surface damage or scoring is caused to the valves, pistons, or cylinders of the engines by the use of superheated steam, if metallic packings are employed for the stuffing-boxes, and the cylinders lubricated with oil of the best quality. The effect of steam-jackets was diminished, and was even found detrimental. In all the engines experimented upon, steam was used in the jackets only to heat the cylinders before starting, and shut off as soon as the engines were running. These experiments also prove that the less the difference between the temperature of the cylinder-walls and of the entering steam, the less condensation there will be during admission, and the smaller the gain by superheating. The tests do not throw much light on the question of steam-pipe loss. In some trials the loss by radiation was about 1° Fahrenheit per $3\frac{1}{4}$ feet, and in others much more; but it is absolutely necessary in all cases to protect the pipes with the utmost care, and the superheater should also be carefully covered to prevent radiation.

The Author concludes by stating, as his opinion, that the use of superheated steam, as exemplified in practice for the last year or two in Alsace, gives practically satisfactory results, and can be safely recommended. A considerable economy may always be realized, but the extent of saving will depend on the construction of the engines, and the rate at which the boilers are worked.

B. D.

The Final Improvement of the Steam-Engine.

By Dr. R. H. THURSTON.

(Proceedings of the United States Naval Institute, 1891, p. 497.)

In its principal features the steam-engine of to-day is the engine of James Watt. It has been brought to a perfection of construction, but no radical changes have been introduced. So much improvement has been effected in the economical operation of the machine that the margin left for further gain has been brought down to a small fraction, and it is important to ascertain the extent and character of the wastes remaining to be reduced or exterminated.

- With the best engines this total waste, apart from the distinctively thermo-dynamic, and so far as known unavoidable rejected heat, consists of three principal parts: (1) heat lost by conduction and radiation externally; (2) heat wasted through the action of the metal of the cylinder internally; (3) the waste work of friction of engine. The first may be taken as rarely exceeding 5 per cent., and the last varies from 5 per cent. in non-condensing to 10 per cent. in condensing-engines. The principal loss remaining is due to the alternate storage of heat in the metal of the cylinder, and its later transfer to the rejected fluid passing into the condenser or atmosphere. Jacketing, superheating, and compounding all tend to reduce this waste, but they do no more than alleviate the evil which neither can completely cure. The one as yet unsuccessful, but obviously correct method of annulling cylinder-condensation is the reduction of the heat-storage power of the walls of the cylinder. This may be done either by reducing its conductivity or its specific heat, or both. Smeaton lined his piston and cylinder covers with wood, Emery with glass or porcelain, and Babcock with bismuth and other similar metals. The Author has proposed to treat the interior surfaces with a veneer or varnish, but all of these processes have presented difficulties. If the surface of cast-iron is subjected to oxidation it is changed to a plumbago-like substance, consisting of iron oxide and graphitic carbon engaged in a sponge or comb of metallic iron, and its specific gravity and conductivity are reduced to a fraction of the same quantities in the original metal. It occurred to the Author that this process and result could be utilized, not upon the rubbing surfaces, but on the cylinder covers and ports where the waste mainly occurs. It was further apparent that the spongy mass might be saturated with some material having a high value as a non-conductor. It has been found by experiment that a cylinder cover treated with a solution of sulphuric acid and water for forty-eight hours, then oiled with linseed oil and allowed to dry twenty-four hours, has its resistance to heat transmission increased 40 per cent. It was also found that a single coating of coach varnish reduced the conductivity to the same extent. The Author, therefore, proposes to treat the surfaces bounding the clearance spaces of a steam cylinder with an acid solution, and afterwards to apply a varnish consisting of several coats of drying oil. This varnish is relied upon to retard the interchange of heat, and the alteration of surface produced by the action of the acid is expected to render the varnish more adhesive and permanent. In this way the waste would probably be reduced at least 40 per cent.

A full account of the experiments is given, describing the different treatment to which plates were subjected, and the method of measuring the charge of conductivity produced.

The article is illustrated by cuts.

S. W. B.

On Surface-Coolers for Injection-Water. By H. BETTINGER.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxxvi., 1892, p. 104.)

The Author, having been led by the rise in the price of coal to adopt a condenser to a non-condensing steam-engine of 70 HP., and being unable to obtain a fresh supply of cold well-water for more than ten minutes at a time, was obliged to resort to the principle of artificial cooling in order to use the same water continuously. After discussing several methods, such as cooling-tanks, open graduation works and others, he describes the plan adopted, which is to divide the hot water into narrow streams which fall through a system of vertical channels against a rapid current of air moving in the opposite direction. In the first form the apparatus consists of a rectangular wooden tower, 7.5 metres high, 1.9 metre long, and 1.3 metre broad, the upper half of which is divided into narrow passages by twenty-six boarded partitions spaced 10 centimetres apart, while the lower half is an air chamber supplied by a fan with spiral blades 1.2 metre in diameter, fixed in one of the sides. The water to be cooled is delivered from a pipe at the top and passes through the intervals between the boards against the upward current of air which moves at about $6\frac{1}{2}$ metres per second. The effect is twofold; the air acting partly by directly absorbing heat, and partly by evaporating and absorbing water vapour, the relative value of these two factors being different at different times of the year. In winter the air works principally by direct cooling, but in summer, when its absorptive capacity for vapour is increased two and a half fold, the cooling is mainly due to evaporation; the final result being tolerably constant throughout the year, the vacuum in the condenser varying between 70 and 73 centimetres of mercury. The cooled water is reserved entirely for condensing, being too greasy for feeding boilers, so that it is constantly receiving new water in the discharge from the condenser. Theoretically, therefore, this should give some increase of volume in the circulating-water, after allowing for evaporation to the air, but in practice it is found that the quantity is constant, except occasionally on the coldest days of winter, when a small amount is sometimes run to waste from the collecting cistern, which is placed underneath the air-chamber.

A curious consequence of the use of the same water over and over again for condensing, is that a higher vacuum is obtained from it than might be expected from its temperature. Thus in five comparative experiments, the same reading of the vacuum gauge (70 centimetres) was obtained with the same water, returning at intervals of ten minutes to the condenser as with fresh well-water; the temperature in the former case being 27° to 28° Centigrade, and in the latter 12° to 13° . This is due to the circumstance that the rapid circulation causes the injection

water to be practically free from air, while in the case of spring- or other natural waters the air-pump has to remove the dissolved gases, and thus a worse vacuum is obtained than with distilled water. It might be supposed that the intimate mixture of water and air would lead to reabsorption of the latter, but this does not take place, partly from the short time of contact, but more particularly from the circumstance that the energy promoting separation of air in the air-pump is measured by the pressure of the atmosphere, or 10,300 millimetres water pressure, while that of the air blast is only 5 millimetres, or $\frac{1}{2060}$ th part of the former.

The space required for the apparatus is only about $\frac{1}{100}$ th of that of a cooling-pond; a surface of 3.5 square metres being sufficient for 100 HP., that of the boards being calculated at 3 square metres per HP. The air-pressure is 5 millimetres of water, the velocity 6.5 metres per second, and the volume required about 2,000 times that of the water, about 2 per cent. of the latter being absorbed as vapour. In order to promote intimate contact between air and water, it is found to be better not to use boards in single lengths of the full height of 6 metres, but to divide them, placing the lower half at right-angles to the upper one, whereby any dry kernels of air from below are brought into contact with the wet surfaces in the upper part. Care must be taken to lay the water on to the boards so as to flow smoothly over them and to prevent all spiriting. The cooling effect of the apparatus when the boards are placed horizontally is only one-half of that of the vertical form.

The wear of the apparatus is very small, the fatty matters brought over by the condensed steam are partly deposited in fine films on the surface of the boards, and protect them from rotting, while the remainder collects on the surface of the water of the tank and is collected at intervals of two months for conversion into waggon grease. The load on the engine is increased by about 3 per cent. by the work of the fan, and from $1\frac{1}{2}$ to 3 per cent. by the circulating arrangement, which may be effected by the air-pump directly or by a centrifugal pump. As the advantage gained by condensing is about 30 per cent. in an engine of moderately good quality, the net saving is about 25 per cent. Numerous examples of the application of the method to engines of different kinds are given in the Paper. It has been adopted, or is in course of construction, in thirty-five different establishments, the largest example being on a central condensing plant for engines of 2,500 HP., at the iron- and steel-works of Dudelingen in Luxemburg.

H. B.

Water-Rams in Steam-Pipes.

By CHAS. E. EMERY, Ph.D., M. Inst. C.E.

(Journal of the American Society of Naval Engineers, 1891, p. 407.)

If steam be introduced below the surface of water contained in a large vessel, a bubble will be formed which will increase in size until its surface becomes sufficiently extended to condense the steam more rapidly than it can enter, when a partial vacuum will be created, the bubble will collapse, and the water flowing in from all sides at a high velocity, will meet with a blow forming what is called a water-ram.

Such explosions occurring in the middle of the mass create simply a series of sharp noises. But if steam be blown into a large inclined pipe full of water, it will rise by difference of gravity to the top of the pipe in the form of a bubble; and when condensation takes place, the water below the bubble will rush up to fill the vacuum, giving a blow directly against the side of the pipe. As the water recedes the bubble gets larger, and moves farther and farther up the pipe, the blow each time increasing in intensity, because the steam has passed a larger mass of water, which is forced forward by the incoming steam to fill the vacuum.

The maximum effect generally occurs at a closed end. Even if the water does not originally extend to the end of the pipe, if this be filled with steam which has bubbled through water on its way to that point, there may be sufficient cold metal to condense it, and when collapse takes place, the whole mass of water in the pipe is driven against the end sometimes with sufficient force to rupture it.

A dangerous water-ram may be produced in a pipe filled with water, even if the end be open, should the pipe be crowned upward at any part of its length. A bubble will form at the top of the crown, and there collapsing, water will be forced in by atmospheric pressure from one end, and by steam-pressure from the other, and the meeting of the two columns may rupture the pipe. The same action can occur in a level pipe, but not in one which descends away from the entering steam, so that the latter is always above the water.

S. W. B.

New Rotary Steam-Engine. By R. SENNEVOY.

(Le Génie Civil, vol. xix., 1892, p. 369. 1 Fig.)

The Author remarks that many attempts have been made to produce a practical rotary steam-engine, but the great speed at which such motors run, varying from 1,000 to 3,000 revolutions per minute, has caused a large consumption of steam, as it is impossible to use the steam expansively without employing

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distributing valves. The inventor of this rotary engine is Mr. Demerliac, and he has attempted to obtain similar conditions as are met with in the Corliss, Sulzer, and other engines. These advantages are a slow speed of from 30 to 120 revolutions per minute, an early cut-off, and valves by which the cut-off opening of the exhaust may be obtained instantaneously. The motor consists of a carefully bored cylinder, provided with machined covers; upon the outside of the cylinder are four valve-chests placed equidistantly round the circumference, and each valve-chest is provided with a Corliss valve. The valves are worked automatically by the engine, and any required degree of expansion may be obtained.

Inside the cylinder are fitted two steam-tight pistons, each being a sector of a circle and equal to a quarter of the cylinder in volume. Each piston can move through half a complete revolution round the axis. The two pistons are independent, and are fixed upon bosses inside which the centre shaft turns; they can only move in one direction, so that each acts alternately as a fixed base for the other, and the shaft obtains a continuous rotary motion. The faces of the pistons are formed by planes passing through the axis of the engine, and the steam-pressure acts normally to the faces. The Author states that a motor of 3 HP. has been built by the inventor, which works at a speed of 70 to 80 revolutions per minute; it weighs 395 lbs. and its external diameter is 15·2 inches.

E. R. D.

The Transmission and Distribution of Power in Modern Ships.

By NABOR SOLIANI.

(Rivista Marittima, 1891.)

In modern ships power is required not only for propulsion but for a variety of other purposes. In the mercantile service it is adapted for steering, weighing anchor, ventilation, lighting, loading and unloading cargo, and pumping; while for war vessels it is also required for transporting ammunition and working the heavy guns. Amongst the several methods for effecting the transmission and distribution of power, it is important to choose the best system for efficiency, regularity, and economy. Mechanical transmission, whether rigid or flexible, is, except to such motors as are in the engine-room itself, practically inapplicable on board ship, owing to the bulky and heavy gearings, bearings and connections required. Of other methods there are four to be considered, viz. :—

1. Steam.
2. Hydraulic power.
3. Compressed air.
4. Electricity.

1. The direct circulation of steam to the various motors is the most simple method, and that which is most commonly in use. The chief difficulty to contend with is the sufficient protection of the pipes to minimise the condensation of the saturated steam; and the flooding of a compartment of the vessel through which the pipes pass, would destroy the efficiency of the whole circuit, and disable all the machines on that side of the ship. While, however, the boilers are acting, and the steam is in circulation, the system possesses the maximum of security and continuity; and is, therefore, the best to adopt for the propellers and pumps and all appliances in the engine- and boiler-rooms.

2. Hydraulic power is best adapted only for slow movements of great weights. It is simple and reliable, easily maintained, and gives complete control of all movements. It is not in any way affected by flooding of any compartment through which the circuit passes. It is well suited for moving and working the heavy guns, as well as for steering and for lifting great weights.

3. Compressed air has many points of analogy with the preceding system; but from the elastic nature of the circulating medium it is not so precise or reliable. It is suitable for machines at any rate of speed, and requires only a supply-pipe, as the exhaust-air does not return to the generator, but performs, without further special appliances, the most important function of assisting the ventilation—one of the most difficult matters to accomplish in large vessels. It is not impeded by the flooding of any compartment on the circuit; and, by the arrangement of suitable valves, the service can be adapted to steam-supply in case of any emergency. There is, therefore, considerable scope for the use of compressed air.

4. Electricity is peculiarly adaptable for the transmission of power to considerable distances, and its distribution to any number of motors in any position whatever. The velocity can be varied to any extent, and the system is subject neither to radiation nor to freezing, and is easily controlled. It is especially suited for high velocity, so that gearing must be interposed to reduce to ordinary speed. The chief disadvantages of the electric current are its uncertainty and its delicacy. The system has yet to be developed before it can be considered as absolutely reliable; and whereas a leakage in any of the preceding circuits can be easily detected and attended to, the location of a point of interruption in the electric current, and the reinstatement of the circuit are matters of considerable skill and time. These and other drawbacks in the matter of exposure of the wires and motors considerably limit the applications of electric power.

In a first-class ironclad of the type of the *Re Umberto*, the auxiliary machines number sixty-nine, and represent a total of 2,480 HP. Not more than half of these, or say 1,200 HP., are, however, acting at one time, even during an engagement. Upon the basis of 1,200 HP., the systems above discussed may be compared in respect of (1) weight of motors and connections,

(2) cubic capacity required for same, and (3) cost of system, as under:—

System.	Weight.	Volume.	Cost.
	Tons.	Cubic Feet.	£.
1. Steam. . . .	104	3,350	13,780
2. Hydraulic power	425	10,240	49,100
3. Compressed air .	290	9,040	36,750
4. Electricity . .	310	9,600	89,000

The Author therefore states as his conclusions upon the subject that, in all respects, steam-power is the most generally convenient. If other systems are used for auxiliary purposes, it is advisable to retain steam-power for all machinery forming integral portions of the propulsion and manœuvring of the vessel; to work the heavy guns by hydraulic power; ventilators, lifts, various pumps and turret machinery by compressed air; and small guns and lighting by electricity. In the case of a first-class ironclad, as above referred to, the power would be thus distributed:—

	HP.
1. Main engines, feed-pumps, condensers, air-compressor, &c.	21,650 steam power.
2. Heavy guns	120 hydraulic power.
3. Ventilators, lifts, pumps, and turret-machinery	1,550 compressed air.
4. Small guns and lighting	120 electricity.
Total	<u>23,440</u>

P. W. B.

Production of Coal in Belgium. By E. HARZÉ.

(Annales des Travaux publics de Belgique, xlix., 1891, p. 206.)

In 1890 the Belgian Collieries produced 20,365,920 tons of coal valued at 268,563,000 fr. or £10,740,000, being the largest yield realized in one year up to that date; the value, however, having been exceeded in 1873 when 15,778,401 tons sold for £13,505,000. The contributions of the different provinces to the above total were:—

	Tons.	Francs.
Hainault	14,768,520	191,380,000
Namur	541,009	5,926,000
Liège.	5,056,481	71,197,000
	<u>20,365,960</u>	<u>268,503,000</u>

When compared with the preceding year (1889) the increase in quantity is 495,940 tons at £3,231,400, and in value the average price per ton having advanced to 13·80 f., or 3·73 f. above that of 1889.

The colliery consumption amounted to 1,873,319 tons, or 9·2 per cent. of the total output, which represents nearly £500,000 value, which being deducted the net amount saleable was 18,490,601 tons, and the price 13·85 f. The highest average prices were obtained in the Western Mons district 15·17 f., and the lowest 12·78 f. at Cnarleroi.

Two hundred and seventy-five centres of production were at work, or one more than in 1889, seventy-seven others being idle, and eight in process of development.

The number of active pits is constantly diminishing, owing to the concentration in larger undertakings, which have declined to the above total from four hundred and sixty-eight in 1841.

The number of steam-engines employed in the different operations was :—

	HP.
For winding 419, together of	64,338
„ pumping 217, „	31,440
„ ventilation 375, „	16,573
„ other uses 1,094, „	15,193
	127,544

The number of winding-engines has diminished considerably during the past ten years, owing to the abandonment of old pits and the disuse of small engines which are unsuited to the greatly increased depth of the mines, but the power of those at work has been very largely increased.

The pumping-engines were classed as follows :—

	HP.
110 direct-acting	21,067
27 beam-engines	4,487
21 rotatory engines	3,720
59 underground engines	2,166
	31,440
217	

The greater number of the subterranean engines forcing to a great height by single lifts are of recent origin.

The ventilating-engines, like those used for winding, have diminished in number, but are collectively more powerful. Of the older variable volume or cylinder machines there are ninety-five, including seventy-seven of Fabry's construction, while the two hundred and eighty centrifugal machines include one hundred and seventy-one Guibal fans. The great increase in the number of engines applied to other uses is due to the extended application of compressed air for driving, hauling and other underground purposes, and the multiplication of screening- and dressing-apparatus required to make the produce merchantable. The average net

thickness of the seams worked and the depths of the workings in the different districts are:—

	Metre.	Metres.
West of Mons	0·56	531
Centre and west of Charleroi	0·64	343
Charleroi	0·75	428
Namur	0·63	235
Liège	0·73	322
Average of the kingdom	0·67	399

In 1890 fifty-nine mines in Hainault exceeded 600 metres in depth, more than half of them being above 700 and eight over 800 metres. The Saint André pit of the Poirier colliery at Charleroi is the deepest, producing coal 940 metres; but the Sainte Henriette pit of the Charbonage des Produits West of Mons explorations are being carried out at 1,160 metres.

In the province of Liège only one pit is raising coal from more than 600 metres depth, but another is in preparation at 640 metres. The working force of 116,779 persons was classified as follows:—

	Men.	Boys.	Women.	Girls.
Underground	75,315	9,608	3,170	945
Surface	18,111	2,499	4,368	2,763
	93,426	12,107	7,538	3,708

The number of females employed underground has diminished as a whole, and by a law of December 13, 1889, which came into operation on January 1st, 1892, the employment underground of women below twenty-one years of age is prohibited. As compared with the decennial periods ending in 1880 and 1870, the proportion of female mining labour has diminished 55 and 75 per cent. respectively.

The average production per hand underground has diminished from 242 tons in 1889 to 229 tons in 1890, or taking underground and surface labour together, from 184 tons to 174 tons or about 5·4 per cent. The yearly wages rose from 932 f. to 1,117 f., and the total rise since 1886 has been about 43 per cent. For the decennial period 1881-90 the prime cost per ton of coal was 8·90 f., realizing on sale 9·60 f., or a profit of 0·70 per ton; 54·7 per cent. of the price representing labour, and 7·3 per cent. profit.

For the year 1890 alone the corresponding figures were:—Prime cost, 10·30 f.; selling price, 13·18 f.; wages per ton, 6·40 f.; and profit, 2·88 f.

In 1890 2,969,388 tons of coal were carbonized, yielding 2,176,733 tons of coke, or an average yield of 73·34 per cent.

H. B.

The Franke Rock-Cutting Chisel. By J. PILAR.

(Oesterreichische Zeitschrift für Berg- und Hüttenweser, 1892, p. 77.)

This machine, invented by Mr. C. Franke, of Eisleben, and adopted for holing in the copper schist of the No. 1 Otto mine of the Mansfield Copper Mining Company, differs very considerably from previous machines intended for the same purpose; the rotary cutters or percussive drills of the ordinary coal-cutting machines being replaced by a straight-edged chisel actuated by compressed air, which exerts a paring or shaving action on the rock by very short blows repeated with almost infinite rapidity, so that the work is done quietly and almost without perceptible shock. The machine, which cannot be described in detail without the accompanying figure, Plate III, is, speaking generally, a single-acting piston- and cylinder-machine, the piston exerting a butting action by a thick rod on the tool holder on the forward stroke, but returning alone, the withdrawal of the tool being effected by a pair of coiled steel springs. The length of stroke is 11 millimetres, during which no work is done for $9\frac{1}{2}$ millimetres, the accumulated energy being delivered upon the tool carrier in the final travel of $1\frac{1}{2}$ millimetre. The return stroke is made by admitting the air on the forward side of the piston, the distribution being effected by a light annular slide made of aluminium carried in a groove in the circumference of the piston which moves backwards and forwards with the latter, but has an independent travel of about $1\frac{1}{2}$ millimetre. The piston is perforated by tubular passages, three to the front and three to the back, which serve alternately as admission- and exhaust-channels, the final exhaust being through the centre of the piston rod. The whole of the working parts are enclosed in a small tubular case about 1 foot long and $2\frac{1}{2}$ inches in maximum diameter, which is connected to the air main by a right-angled delivery pipe of 16 millimetres internal diameter. The piston diameter is either 45 or 50 millimetres. With air at 4 atmospheres the machine makes about eight thousand strokes of $1\frac{1}{2}$ to 2 millimetres per minute when at work; but when running unloaded the number, as determined by a counter specially made for the purpose by Messrs. Siemens and Halske, is as high as fifteen thousand. The cutting tool is a tapered straight-edged chisel about $\frac{3}{4}$ inch in length of face.

The thickness of the bed of schist being only about 37 centimetres it is necessary to take out a certain amount of waste rock to make room for the hewers, who work lying on their sides, the effective height of the working varying from 40 to 58 centimetres. The system followed is that of long walls to the rise, the seam having a dip of from 6° to 10° , and the back walls are kept at a distance of only about 1.5 metre from the face, so that no props are required. The extra height is taken in the roof of the seam as being more easy to cut than the floor. Originally the machines

were mounted upon frames with wheels, but on account of their small weight, from 9 to 13 lbs., it is found preferable to support the machine by hand, the hewer lying on his side holding it in the left hand with the bend of the air pipe bearing against the left thigh. The action is almost imperceptible, except as a rapid vibrating motion, the detritus coming away rapidly and quietly in fine shavings a few centimetres long.

The working length of face allotted to one machine is from 2.2 to 4 metres, averaging 3 metres. This is holed to a depth of 50 to 60 centimetres, the height of the cut tapering from 14 millimetres at front to about 2 at the back at the rate of about $\frac{1}{2}$ square metre per hour. When the cut is completed, a boring-machine is attached to the air-pipe, and holes 5 to 10 centimetres deep are bored near the roof at intervals of 1.5 metre along the face, each of which receives a cartridge of gelatine dynamite 4 centimetres long and 18 millimetres in diameter. These boring machines have the same kind of valve as those used for under-cutting with the addition of a reversing-gear.

The compressed air is supplied by small rapidly-moving slide-valve compressors of Burckhardt and Weiss's pattern, making 80 to 120 revolutions per minute, and furnishing air at 6 atmospheres pressure. The distribution is effected by pipes of three sizes, the shaft main and that of the principal roads being 100 millimetres bore and 4 millimetres thick, the intermediate pipes in the working roads and inclines 64 millimetres bore and 3 millimetres thick, and those along the working faces 30 millimetres wide and 2 millimetres thick.

For storing compressed air underground and in the rock are becoming very general. There are levels of rectangular section 3 metres high, 2½ metres broad, about 10 metres long, closed by an arched dam in masonry with an internal facing of 5 centimetres of cement. The walls are made airtight by covering them with cement mortar, which, being subjected to full air-pressure while still soft, is driven into the cracks and hollows of the rock. When hardened the process is repeated as often as may be necessary until an airtight chamber is obtained. There is a tube and man-hole on the dam, and a regulator which keeps the air at a constant pressure of 4 atmospheres as required by the machines.

The Author also notices a similar machine by Mr. James MacCoy, of Boston, which was exhibited at the Paris Exhibition in 1889, and gives a comparison of its details with those of Franke's machine.

H. B.

Boring-Exploration in the Daltongunj Coalfield.

By T. D. LA TOUCHE.

(Records of the Geological Survey of India, vol. xxiv., p. 141.)

The investigation of the Daltongunj coalfield, by means of borings, was undertaken with the object of testing the capabilities of the field for the production of coal in sufficiently large quantities to warrant the construction of a railway that should make the coal available for use in Upper India. The conclusion arrived at, unfortunately, was that former estimates, both as to the quantity and the quality of the coal, were too favourable, and although there is undoubtedly a large amount of coal available, yet the conditions of its distribution are such as to render it extremely doubtful whether a sufficiently large output could be obtained to warrant the construction of the railway contemplated.

The thickness of the first seam is shown by the borings to vary from 1 foot 6 inches to 7 feet 6 inches, and that of the second seam from 29 feet to 6 feet or less. The results of the assays of these coals are somewhat disappointing, the amount of ash in most of the samples being higher than that generally considered admissible in a serviceable fuel. It would, however, be advisable, before condemning the coal on the results of these assays, to extract a sufficient quantity from the thick seam to enable a trustworthy estimate to be formed of its quality by testing it under steam-boilers.

The Paper is accompanied by tabulated records of the borings, tables of assays, and a coloured geological map of the coalfield on the scale of 4 inches to the mile, showing the positions of the borings.

B. H. B.

Coal-Dust Explosions at the Zauckerode Colliery.

By MAX GEORGI.

(Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1891, p. 1.)

The seam, 3 to 5 yards in thickness, worked at the Zauckerode colliery in Saxony yields a dust of the class described by Atkinson as especially dangerous. Fortunately the dust is present only in small quantities. Three explosions, however, that have recently occurred, show that under certain conditions this dust may be a source of danger. The methods adopted in order to obviate its disastrous consequences, consist in the employment of flameless explosives, and of appliances for artificially moistening the dust by means of a water-spray.

The flameless explosives in practical use are flameless dynamite (*Wetterdynamit*), roburite, securite and carbonite. The first of

these contains, as aqueous salt, magnesium sulphate. The best results with this class of explosive were obtained with flameless kieselguhr-dynamite with 40 to 45 per cent. of nitro-glycerine. Experience showed, however, that all flameless dynamites deteriorated with keeping, and all evolved noxious gases. Roburite was found to be uncertain in its action, and it was thought to be not homogeneous, or to be subject to spontaneous decomposition. The use of roburite and of flameless dynamite has been abandoned at Zauckerode; but satisfactory results have been obtained with securite and with carbonite. The latest form of carbonite is a nitro-glycerine explosive mixed with a sufficient quantity of carbonaceous matter to prevent the formation of free oxygen or of carbonic oxide. Securite consists, so far as is known, of nitro-benzol and ammonium nitrate. With reference to the storing of these explosives, the same precautions must be taken with carbonite as with gelatine-dynamite. Securite, however, is not affected by changes of temperature, but is very sensitive to the action of moisture. Carbonite can be completely exploded by a detonator with a charge of 0·8 gram, whilst securite requires 1·5 gram. The former is found to act best in coal and in soft rocks, and experience at Zauckerode tends to show that it may be used as a substitute for blasting-powder in most collieries, and that it must eventually entirely replace dynamite, which is still used here and there. Securite, as a more powerful explosive, is not adapted for soft coal. Its use is, therefore, confined to hard pyritic coal or to hard rock. The amount of coal wrought by the miner is less with carbonite than with powder; but in narrow headways, the length driven is not affected by the use of flameless explosives. The cost of blasting is in all cases higher than when powder is used.

The second method of obviating coal-dust explosions consists in the employment of appliances for moistening the dust. The installation of pipes was begun in May 1890 in the workings in the vicinity of the Carola shaft, where the air is driest and the dust, as is proved by the explosion that occurred there, most dangerous. The water was taken from a drainage-level some 270 feet above the workings in question, and an ample supply was available. With the exception of the cast-iron mains, all the pipes are of galvanized wrought-iron. The use of the spray, the construction of which is shown in drawings accompanying the Paper, is confined to the actual workings. The installation extends to sixty working places, and cost £1,700.

B. H. B.

Breakage of Winding-Ropes in Saxon Mines. By C. MENZEL.

(Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1891, p. 39.)

Since 1884 the law has been enforced in Saxony that all breakages of winding-ropes and chains shall be notified to the mine-inspectors. The returns obtained in this way show that during the seven years ending 1891, there were in all one hundred and thirty-three breakages of ropes and chains in the Saxon mines. Of this total, thirty-two occurred in metalliferous mines, ninety-seven in collieries, and four in lignite mines. The breakages during the various years were as follows:—

Year.	Metal Mines.	Collieries.	Lignite Mines.	Total.
1884	4	23	1	28
1885	2	20	1	23
1886	1	24	..	25
1887	3	12	1	16
1888	6	6	1	13
1889	9	8	..	17
1890	7	4	..	11

From these figures it is seen that, in the case of the collieries, although the output increased $5\frac{1}{2}$ per cent. from 1884 to 1888, and then decreased, the number of breakages has considerably diminished, whilst the depth of the shafts has continuously increased. The majority of breakages, as would naturally be expected, occurred as the cage was being raised; in only eighteen cases the breakage occurred as the cage was being lowered. The causes of the accidents cannot be ascertained with accuracy. Some forty-three of the cases were, however, undoubtedly due to bad or worn material, five to seven were due to imperfect welding, twenty to friction on the pulleys, and twenty to the jamming of the cage or kibble in the shaft.

The question whether it is desirable to have safety-catches, or merely to trust to the rope being of good quality, is not yet definitely decided by mine-managers. In the seventy-nine cases in the collieries in which safety-catches were provided, they came satisfactorily into action in sixty cases, or in other words seventy-six times in one hundred. These results certainly appear to be in favour of the adoption of safety-catches. The Paper, which covers forty-three pages, contains full details of each of the 133 breakages.

B. H. B.

The 4,000-ton Forging-Press at Bochum. By R. M. DAELÉN.

(Stahl und Eisen, vol. xii., 1892, p. 165.)

The Bochum Mining and Steel Company have taken to the use of hydraulic presses for forging steel ingots on a considerable scale, the largest being of 4,000-ton squeezing-power. This is constructed on Fritz Baars' patent, with a central ram divided into two parts, of unequal diameters, the lower half being 930 and the upper 530 millimetres, and arranged for three different working pressures in the proportion of 1 to 2 to 3, the effect in these cases being 1,300, 2,700, or 4,000 tons, at a maximum pressure of 600 atmospheres. The lift of the ram is 1,500 millimetres, and is invariable, the cross-head carrying the cylinder being fixed and not adjustable in height, like the presses made by Messrs. Tannett, Walker and Co. The return-stroke of the ram is made by two 260-millimetre plungers, which are subjected to a pressure of 50 atmospheres, and also serve as guides for the down stroke. All the parts are cast in steel, the top cross-head, which is in two pieces, weighs 64 tons, and the cylinder of 35 tons weighed 57 tons in the rough casting. The press is manipulated by a slide-valve, moved by a lever which has only 600 millimetres' travel, and requires an effort of only 3 kilograms, being only subjected to the lower pressure of 50 atmospheres, the same pressure being used for moving the high-pressure admission and exhaust-valves by means of pistons. The path of the hand-slide is divided into three parts; the first opens the exhaust, the second the 50-atmosphere admission, and the third that for 600 atmospheres, the latter being only admitted when the ram is actually in contact with the ingot or block, and work is required to be done upon it. This makes the press very economical in work, the 4,000-ton pressure being obtained by a twin steam-pump, with cylinders 760 millimetres diameter and 920 millimetres stroke, cutting off at one-fifth, and making 30 revolutions per minute. The accumulator, with a compressed-air resistance, has a plunger 225 millimetres diameter, and a length of stroke of 3 metres. The lower-pressure water is provided by a pair of engines 460 millimetres diameter and 700 millimetres stroke, pumping into a dead-weight accumulator of 450 millimetres diameter and 3.5 metres lift. The engines for both high- and low-pressure water, and the accumulator for the former, are provided in duplicate.

The press stands in the centre of a forge 33 metres in diameter, the top forming the pivot for a radial crane 275 tons of lifting-power, whose outer pillar travels on a circular railway, the heating furnaces being arranged round about two-thirds of the circumference, in the same manner as in the large hammer forges at Bochum and Terni; there are also two pieces of apparatus for turning the work, which can be used in addition for drawing and charging the heats. These, together with the crane, are driven by the 50-atmosphere accumulator.

The work done by the press is about double that of a steam-hammer of equal power in the same time, the consumption of steam and cost of maintenance being considerably less.

H. B.

The 4,000-ton Forging-Press at Montluçon. By — DEMENGE.

(Le Génie Civil, vol. xx., 1891, p. 65. 14 Figs.)

Hydraulic presses for forging are now used in many cases instead of steam hammers for heavy work; this is especially the case for steel ingots, as the work is found both more regular and more rapid, and the difficulties of arranging a solid anvil-bed are obviated. The Author states that the Compagnie des Forges de Châtillon-Commentry has installed a forging-press of 4,000 tons capacity at the works of Saint-Jacques, at Montluçon; this is stated to be the most powerful press yet made in France. The press is specially intended for forging large ingots and forming armour plates. The building in which it is placed is a metal shed 59 yards long, 24 yards wide, and 51 feet high at the entrance; a smaller shed is built alongside the former which contains the compressing-pumps, accumulators, and boilers; two re-heating furnaces are placed close at hand. The roof of the shed is supported by metal columns spaced 29 feet 6 inches from centre to centre, and these also support the travelling cranes. The press itself is not placed in the centre of the shed but at a distance of about 10 feet from the centre line, and on the side opposite to the re-heating furnaces; this allows more space for working. The press consists of two frames bound together by four steel columns solidly bolted. The upper frame is fixed, and carries at its centre the high-pressure cylinder which is used for forging. The lower frame consists of two girders solidly fixed to the foundation, and upon these the anvil may be moved. It is provided with two low-pressure cylinders which allow the tool to be taken out when not in use. The upper frame consists of two heavy steel plates 7 inches thick, strengthened by cross pieces, and held by twelve bolts to cast-steel cross-bars through which the piston rods of the low-pressure cylinders pass. The principal cylinder is made of forged steel and has an internal diameter of 3 feet 7½ inches; the thickness of the metal is 11·8 inches; the top of the cylinder is closed by a screwed disk provided with a hole at the centre, by which the high-pressure water enters; all leakage is prevented by the use of a leather washer, kept in position by an iron plate tightened upon the disk by means of bolts. The compressing piston is of cast-iron, and is hollow; at its lower end a core of wrought-iron is let in and this transmits the pressure to the movable cross-head; the upper surface of the piston is slightly rounded, which permits it to be raised to the top of its stroke

without stopping the work; at its upper part it is provided with a U leather held between two steel rings. The cross-head consists of a girder composed of two vertical plates 2 feet 11½ inches high, joined together by two horizontal plates 3 feet 9 inches wide; all the plates are of steel 0·98 inch thick. The girder is 19·6 feet long and occupies the whole width of the press; at its centre it carries a tool-holder formed with a dove-tail in which the various tools may be fixed. At each end one of the pistons of the elevating cylinders passes through it and is attached solidly by means of nuts. The lower frame consists of, first, two strong girders made of steel plates 5 feet 7 inches high, strengthened by means of angle irons let into the masonry, and firmly fixed into the foundation by means of bolts 2·35 inches diameter. These girders run across the press, while, in the direction of the length of the press, two similar girders 2 feet 11 inches high rest upon the first and act as supports and slides for the anvil-block; the latter is of cast-iron, and is in two pieces, joined together by eight wedges. The working tools are fixed by means of studs. The lower part of the anvil carries two lugs at the front, to which are attached the two piston rods of the horizontal hydraulic cylinders, placed at the back of the press. The horizontal movement of the anvil which is thus obtained facilitates the changing of the tools as well as the movement of pieces of metal which are being worked. The elevating cylinders are solidly bolted to the cast-iron supporting girders of the four mild steel columns which act at the top and bottom frames of the machine; these cylinders are of cast-iron smelted from hematite ore of the best quality, and are bored to 20·75 inches diameter in their whole length to receive the forged steel piston guides, which we have previously alluded to. These cylinders are in constant communication with a low-pressure accumulator. The stroke of the forging piston is 8 feet, and the distance from centre to centre of the columns 16 feet in one direction, and 8 feet in the other.

The Author describes the arrangements of high-pressure pipes and the hydraulic accumulators which are used for the press; and states that the high-pressure pipes are subjected to a pressure of 3·5 tons per square inch; they are made of mild steel of 3·5 inches internal diameter, and 6·4 inches external diameter. The low-pressure pipes are designed for a pressure of 0·35 ton per square inch; they are of wrought iron, with an internal diameter of 2·95 inches. A description is then given of the furnaces and of the travelling-cranes, and this is followed by details of the compressing engines, the pumps, and other subsidiary work.

E. R. D.

On the Loss in Dressing Mixed Lead-Ores in Germany.

By MAURICE BELLOM.

(Annales des Mines, vol. xx., 1892, p. 81.¹)

The Author gives three examples of complete treatment of lead and silver ores of different characters, from Himmelfahrt and Churprinz mines at Freiberg and from Ems, in Nassau.

Himmelfahrt.—The vein-stuff of this mine, derived from the so-called pyritic lead formation, contains galena assaying 70 to 85 per cent. of lead, and 0·2 to 0·3 per cent. of silver associated with blende (35 to 40 per cent. zinc, and 0·03 to 25 per cent. silver), iron and arsenical pyrites, both poor in silver (0·005 to 0·20 per cent.), and copper pyrites (20 to 35 per cent. copper, and silver 0·039 to 0·06 per cent.). The waste contains quartz, spathic iron ore, barytes, dolomite, fluor calcite, and, occasionally, fragments of the country rock, gneiss, and mica schist. In bulk the metallic contents are—lead 2·75, zinc 0·275, silver 0·023, arsenic 0·5, copper 0·01, and sulphur 0·005 per cent. The treatment is a combination of hand-picking, sorting by dry-sizing sieves, jigging, stamping and washing on percussion-tables, and, to a small extent, crushing by rolls. As a whole, about 25 per cent. of the stuff is hand-picked, and 75 per cent. goes to stamps. The sizing-sieves give for the picking-table 28, for stamps 21, for spalling and cobbing 21, and small *grubeklein* 30 per cent.; the first three kinds, making 70 per cent. of the total extraction, are subjected to treatment without water, giving waste 35, stamp-stuff 22, crusher stuff 6, and finished ore 7 per cent. The proportion requiring to be treated with water is, therefore, 58 per cent., made up of the following items: smalls 30, stamp-stuff 22, and crusher stuff 6 per cent. The smalls in the jigging process give 40 per cent. of stuff requiring further reduction by stamps and rolls, and the crusher gives 30 per cent. of stamp-stuff. The 28 parts of stamp and crusher stuff contain 17 that are treated in the washing processes proper, which, added to the 58 parts, makes 75 per cent., or the figures previously given, as the proportion to be stamped and washed.

The quantity of material handled on the picking-tables is 98 cubic metres, or 196 tons per week.

The finished lead-ore is dressed up to lead 85, and silver 0·3 per cent.; the blende to zinc 40, and silver 0·03 per cent.; and the pyritic ores to sulphur 40, and silver 0·05 per cent. The losses upon the gross contents of the different components of value are—silver 21, lead 38, and sulphur 60 per cent.

These high losses are largely due to the presence of an intimate mixture of pyrites and blende in the vein-stuff, both argentiferous,

¹ This is an extract from a long descriptive memoir of 185 pages on the "Dressing of Minerals in Saxony, the Harz, and Rhenish Prussia."

but which cannot be separated and therefore useless for smelting. This amounts to, and sometimes exceeds, 20 per cent. of the stamp-stuff. Comparative experiments, with a view of substituting crushing-rolls for stamps, have resulted in favour of the latter; the proportion of merchantable products being four times the value of that obtained by the former, for, although the loss of lead is larger, there is a considerable quantity of silver saved in dry or pyritic slimes by the stamps, which are saleable to the smelters, but remain as intractable intermediate products when the reduction is effected by the crusher.

Churprinz.—The vein-stuff of this mine contains lead 3, and silver 0·0095 per cent.; it is dressed up to lead 70, and silver 0·05 per cent. The losses calculated on the gross contents are—silver 22·8, and lead 14·9 per cent.

Ems.—The mineral treated at Ems contains lead 4, zinc 2·5, and silver 0·0054 per cent. The lead ore is only concentrated up to a yield of lead 36, and silver 0·030 per cent., while the dressed blende assays 44·5 per cent. of zinc, and is not argentiferous. The losses on the initial contents are—silver 8, lead 6, and zinc 34 per cent.

H. B.

The Application of the Bessemer Converter to Lead-Smelting.

(*Revue Universelle des Mines*, vol. xvii., 1892, p. 110.)

At the Friedenshütte steel works in Upper Silesia, experiments have been made by Dr. Rösing, formerly manager of the Tarnowitz lead works, on the substitution of the basic lined Bessemer converter for the test in the refining of argentiferous lead. A charge of 6 tons of furnace lead heated somewhat above its melting-point was blown for twenty-five minutes with air at 22 lbs. pressure. The action was extremely energetic; the litharge produced being raised to 1200°, became extremely fluid, and was entirely converted into the crystalline or flake form in solidifying. The original lead containing about 15 ozs. of silver per ton, was enriched to 238½ ozs., while the litharge contained about 1½ ozs., which quantity it was thought might be reduced in regular working. The fume contained 75 per cent. of lead, and 4 dwts. of silver.

A sample of desilverized lead from the Parkes process, containing zinc, when treated in the same manner for a few minutes, gave a refined metal of the following composition:—

Antimony.	0·0007	Iron	0·0022
Arsenic	0·0005	Zinc	0·0015
Copper	0·0013	Silver	0·0004 (2 dwts. 15 grains).
Lead by difference	99·9934,	or a total of foreign substances of	
2 ozs. 3 dwts. per ton.			

The lining of the converter stands the action of the litharge

perfectly, the wear being considered to be less than is experienced in making very mild steel. The heat developed during the blow being very great, there is no necessity for warming the converter between the charges, and in continuous work it might be possible to utilize a portion of the excess heat so produced in melting a portion of the charge.

During the blowing there is a very dense emission of lead smoke, but the proportion volatilized as compared to the weight of the charge is comparatively small from the short time that the operation lasts, and it is easily collected, being only mixed with the nitrogen of the air consumed, and not with furnace gases. The economy realized over ordinary refining on the test is said to be about 18s. 9d. per ton of lead treated. The fluid litharge from the converter may be very readily revived by running it over a filtering bed of carbon, heated to redness, which produces instant reduction, or it may be used for the reduction of galena. For the latter purpose the ore is reduced to a coarse powder, and heated to an incipient roasting temperature, when the liquid litharge is poured over it. A very rapid decomposition results with the formation of metallic lead and sulphur dioxide, which being free from air or furnace gases, may be easily condensed.

H. B.

New Electrolytic Methods of Reducing Copper-Ores.

By E. MASSON.

(Revue Universelle des Mines, vol. xvii., 1892, p. 158.)

The following description of new processes for reducing copper ores by purely electrolytic methods is contained in a general memoir on the application of electricity to mining and metallurgy, as shown at the Frankfort Exhibition.

Siemens and Halske's Process.—The characteristic feature of this process is the use of a liquid which dissolves the copper contained in the ore, and gives it up when subjected to an electric current, whereby its solvent capacity is restored so that the same liquid may be used indefinitely. The solvent agent used is ferric sulphate, which is partially reduced to the ferrous salt, with an equivalent production of cupric sulphate. By electrolyzing the copper salt alone is decomposed, and the ferric sulphate is severed.

The ore, when finely powdered by a ball-mill, is heated in a vat with a hot solution of ferric sulphate, the solvent action being facilitated by mechanical agitators, and the liquor, after filtration, passes to the electrolyzing vessel. This contains a series of copper-plates forming cathodes, supported horizontally upon wooden slips at the top, while the anode, formed of carbon rods, is similarly arranged at the bottom, a horizontal filter being placed between them. An agitator, made of wood, is used in the division con-

taining the cathodes. By this arrangement the deposit of copper takes place at the top, while the exhausted new liquor collects at the bottom of the cell, and runs back to the dissolving tanks. The energy required is furnished by an electro motor of 180 watts ($\frac{1}{4}$ HP.), which also drives a dynamo for electro plating, but the yield of copper by this small installation is not given.¹

Höpfner's Process.—This process, due to Dr. Höpfner, of Giessen, depends upon the alternate formation and decomposition of cuprous chloride which, under the action of the electric current, is resolved into copper and chlorine, the former going to the cathode and the latter to the anode, where it is absorbed by the electrolyte with the formation of cupric chloride, which can be employed as a solvent for the ores. For this purpose the electrodes must either be contained in separate cells, or be divided from each other by a diaphragm. The anodes are formed of carbon plate, and the cathodes of copper.

The electrolyte, a solution of cuprous chloride in chloride of sodium, circulates around the electrodes, copper being deposited at the cathodes at the rate of 2.36 grams per ampere hour, by a current of 50 amperes per square metre, or twice as much as is obtained per unit of current in operating with a cupric salt, as in Siemens and Halske's method. If the anodes were exposed, free chlorine, which requires a potential of 1.8 volts for its separation, would be given off, but as they are bathed in cuprous chloride solution, the chlorine is immediately absorbed with the production of CuCl_2 , and a development of energy corresponding to an electromotive force of about 1 volt, so that in practice only a tension of 0.8 volt is required for electrolyzing. The heat of formation of cuprous chloride Cu_2Cl_2 is 65.75 calories, corresponding at 45 calories per volt to 1.46 volts, which represents the electromotive force required to separate it into Cu_2 and Cl_2 apart from the resistance of the circuit, which brings it up to 1.8 volts, below which tension no quantitative decomposition can be effected.

When nascent chlorine acts upon cuprous chloride at the anodes, the following reaction ensues:—



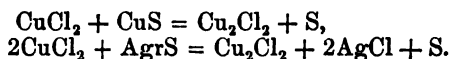
Whence, as 2CuCl_2 represents 125.45 calories, it results that $125.45 - 67.75 = 59.67$ calories are rendered available for the work of the current, so that, theoretically, electrolysis begins when the tension is $65.75 - 59.67 = 6.08$ calories, or 0.15 volt.

The liquor at the cathodes being brought into contact with a continuous series of fresh surfaces becomes almost entirely freed

¹ Another account of this process (*Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1892, p. 91) gives the power necessary for the production of 1 ton of copper in twenty-four hours from 4 per cent. ores as 130 HP., made up of 75 HP. for the dynamos, and 55 HP. for the crusher, agitators, lifts, and other accessory apparatus. The crusher is a Gruson ball-mill which grinds the ore sufficiently free to pass a 90-mesh sieve.

from copper, retaining only the soluble alkaline salt; that at the anodes, on the other hand, retains its copper, but is entirely transformed into cupric chloride, one molecule of CuCl_2 being formed for each atom of copper precipitated. This, as well as that from the cathodes, flows continuously from the decomposing cell, and is received in a storage tank.

The original copper liquor is obtained by acting upon sulphuretted ores ground to a fine powder with the cupric chloride solution, when the sulphide of copper and silver are decomposed according to the following well-known reactions:—



In the latter case the silver chloride dissolves in the sodium chloride contained in the liquor, and the copper reduced is exactly replaced, but in one-half of the original volume of solution. The strength is, therefore, reduced by mixing it with the exhausted liquor from the cathodes, and the process goes on as before in a continuous cycle.

The continuity of the process is only affected by the presence in the solution of iron, arsenic, antimony and bismuth, which should be removed by the addition of cupric oxide, or lime, to the solution before admitting it to the bath.

When the liquor contains silver, it is either deposited electrolytically upon the plates in the first bath, or by chemical means before the deposition of the copper. The latter metal is then obtained in as high a state of purity as any other electrolytic copper.

The advantages of the process are as follows:—

The amount of copper deposited is twice that obtained by the same current from sulphate, so that the plant is smaller.

The chlorides of the alkaline and earthy metals are such powerful solvents of the chlorides of copper that, in the absence of iron, a degree of concentration in the solution is admissible far beyond that possible with sulphate.

As regards the power required, the output of a large dynamo is 690-volt amperes per HP. per hour, or 862 amperes at 0.8 volt.

This at 2.36 grams of copper per ampere hour gives—

$$\frac{862 : 2.36 : 24}{1,000} = 48.8 \text{ kilograms};$$

or, allowing 10 per cent. loss, 43.9 kilograms of copper per HP. per day.

With a boiler consumption of coal of 30 kilograms per HP. per day, supposing one-fourth of the steam power to be used for the dissolving and circulating operations, and three-quarters for the dynamo, it appears that, allowing 19 per cent. loss of current, 33 kilograms of copper may be extracted from the ore by this

process by the expenditure of 30 kilograms of coal, a result that has not hitherto been attained, and allowing the treatment of minerals of the poorest kind.

The process has, in addition to the experimental works at Giessen, been adopted at Schwarzenberg, in Saxony.

H. B.

On the Effect of Heat on Mercury Compounds. By F. JANDA.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1891, p. 583.)

The sulphide, oxide, sub-oxide, sub-chloride, and basic sulphate of mercury are completely decomposed by heat when mixed with forge scale (magnetic oxide of iron) under a covering of zinc oxide, but the chloride shows a loss of 8 per cent., and the normal sulphate of 4 per cent. volatilized unchanged by the same treatment. When the zinc oxide cover is omitted, the mercury obtained from cinnabar is almost always blackened with amorphous sulphide.

Theoretically, the mercury contained in these compounds is as follows:—

Mercuric oxide HgO	92.5 per cent.
Mercurous „ Hg_2O	96.1
Mercuric sulphide HgS	86.2
„ chloride Hg Cl_2 (corrosive sublimate)	78.8
Mercurous „ Hg_2Cl_2 (calomel)	84.9
Mercuric sulphate Hg SO_4	67.5
Basic mercuric sulphate Hg_2SO_4 (Turbeth mineral).	82.4

These figures are realized in the new Idria method of assay with iron oxide and zinc, using a gold dish for collecting the mercury, except in the case of the sulphate and chloride, which gave lower results.

When heated without any reagents, the following facts have been observed.

Mercuric sulphide (cinnabar) is changed to metallic mercury, sulphur dioxide, and, to a small extent, to black sulphide.

Mercuric oxide darkens, and at very low red heat is changed to mercury and oxygen; the salts of this oxide volatilize with partial decomposition. Mercuric chloride volatilizes almost without any change, only about 5 per cent. being reduced to metal, as does also mercuric nitrate, which is but very slightly decomposed by heat.

Mercurous oxide changes at 100° into mercury and mercuric oxide, and by further heating is completely reduced to metal with the separation of oxygen. The salts of this oxide are all decomposed at a red heat. Mercurous chloride is completely volatilized without decomposition. Mercuric sulphate, which is white when cold, turns yellow and melts to a brown fluid, which gives the

original white salt when solidified and cooled. At a higher temperature it is completely volatilized without change, but more slowly than any of the other compounds.

Turbeth mineral, a basic sulphate obtained from HgSO_4 , by washing it with a large quantity of hot water, which results in the formation of free sulphuric acid and yellow turbeth ($3\text{HgSO}_4 + 2\text{H}_2\text{O} = \text{Hg}_3\text{SO}_6 + 2\text{H}_2\text{SO}_4$), is completely volatilized with decomposition when heated for about four times as long as the oxide or chloride.

The mercurial flue-stuff (*stupp* of Idria, *hollines* of Almaden), which is of the following composition:—

Metallic mercury . . .	81.04	} 86.52 Hg.	Calcium sulphate . . .	2.74
Mercuric sulphide . . .	5.76		Magnesium . . .	0.21
Basic sulphate . . .	0.52		Hydrocarbon . . .	2.66
Mercurous chloride . . .	0.12		Carbon (soot) . . .	6.46
Mercuric chloride			Silica . . .	0.15
Ammonium sulphide	} trace.			

decomposes by heat into metal and mercury-black, a finely divided mixture of metal and sulphide. This black powder, when mixed with and distilled under a cover of lime, gives metallic mercury, which also happens when the covering is omitted, and only 25 per cent. of lime is used in the mixture, but with a larger loss. The amalgam obtained on the gold plate is bright, with only a slight covering of a hydro-carbon oil. Mercuric chloride and sulphate are not completely decomposed by lime alone, and the deposited amalgam is covered with a sublimate of the unchanged salt.

When cinnabar, or flue-soot, is mixed, 25 per cent. of lime and 25 per cent. of lamp-black, which contains both carbon and hydrocarbons, and heated for fifteen minutes, the mercury is almost completely recovered, but the deposit is coated with black. The oxide and lower compounds are completely decomposed, giving a clear amalgam by the same treatment; but the higher chloride and basic sulphate show a loss of 8 and 4 per cent. respectively, or the same as in the method of assay with iron and zinc oxides.

H. B.

Magnetic Leakage in Dynamos and Motors. By A. S. IVES.

(The Electrical World, 1892, p. 11.)

The usual method of testing magnetic leakage is by means of a ballistic galvanometer, but it is not always easy to obtain an instrument which is sufficiently ballistic, and to find a place for mounting it beyond the influence of disturbing magnetic fields. The Author therefore attempted to substitute for the ballistic galvanometer an ordinary dead-beat Weston voltmeter, and found that it answered equally well. Some preliminary trials were made on a 3-HP. motor with exploring coils of different diameter

of turns, and it was found that the deflection of the voltmeter needle, caused by the transient current on breaking the field circuit, was strictly proportional to the number of turns in the exploring coil. It was also found that, for low magnetisation, and when using the same exploring coil, the deflection was proportional to the magnetising current. Having thus satisfied himself that the voltmeter was sufficiently reliable for this kind of measurement, the Author proceeded to investigate the magnetic leakage of five different machines, varying from a motor of $\frac{1}{4}$ th HP. to a dynamo of 30 HP. Exploring coils were wound round different parts of the machine, and the deflections were always taken on breaking the magnetising circuit. These experiments are given in detail, with sketches of the machines, and the results are tabulated. The greatest loss by leakage was found in the 30 HP. Edison machine, the ratio of the total to the effective magnetism being 1.64; the smallest loss was found in a 3-HP. Crocker-Wheeler motor, where this ratio fell to 1.21. The same motor was tested with the ballistic method, and the Author found an almost absolute agreement with the voltmeter method.

G. K.

Storage-Batteries in Central Stations. By L. SCHROEDER.

(*Elektrotechnische Zeitschrift*, 1891, p. 585.)

The Author deals exhaustively with the determination of the most economical size of the storage battery, on the assumption that the following particulars are known:—(1) Load curve; (2) Pressure at the feeding points; (3) Loss in feeders; (4) Efficiency of battery. As regards the machinery, he makes the assumption that on the day of greatest demand in winter the engines shall be worked at full power during the twenty-four hours. The method of calculation is shown on an example, for which purpose the Author takes a station supplying, on the three-wire system, 10,000 simultaneously burning lamps, each taking 0.55 ampere at 110 volts. The loss on each side of the zero wire in the feeders is taken at 10 volts, making the maximum station voltage 240 volts. The method of calculating is a series of approximations. First, the Author determines the energy sent out at different hours throughout the day, taking feeder hours into account. The calculated values are plotted for one side of the three-wire system in a load curve. Its area represents the number of units delivered in the twenty-four hours, and this amounts in the example chosen to 1,809.3 Board of Trade units. If there were no loss in the battery this would also be the work obtained from the steam dynamos, and the height of a rectangle of equal area with the load curve would give the output of the dynamos. This is the first approximation, and gives the engine-power too low. The area of

the load curve above the rectangle thus determined, represents the number of units which the battery has to supply. Adding one-third to this (which corresponds with the efficiency of 75 per cent. assumed for the battery) we get a new and larger value for the total units produced by the dynamos, viz., 2,211·4 Board of Trade units, corresponding with an output of 92 kilowatts. This value again inserted in the diagram gives now a slightly reduced area for the battery discharge, and by adding one-third, and again finding the height of the equivalent rectangle, we get as a third approximation 2,176 Board of Trade units for the dynamos.

Continuing the calculation in this manner, the Author finds that the true value for the engine power is 90·8 kilowatts, or a total daily output of 2,180 Board of Trade units, whilst the batteries must deliver daily 869·6 Board of Trade units. This gives for the combined dynamos and engine-plant at the station an efficiency of 87 per cent., 13 per cent. of the total dynamo output being lost in the batteries.

Having thus found the size of dynamos and batteries, the Author proceeds to calculate the rate at which current will be delivered, and finds that the maximum dynamo current will be 776 amperes, and the maximum current from the battery will be 1,743 amperes; the total capacity of the battery being 7,410 ampere hours. The relation between discharge current and capacity is represented by the formula $K \sqrt{C^2} = m$ where K is the capacity in ampere hours, C is the discharge current, and m is a constant depending on the size and type of cell. In the case under consideration the battery would consist of four parallel series of 130 cells each, having jointly the capacity and discharge rate above given.

The Author next considers the case of a central station in which the steam plant is run for twelve hours only per day, thus doing away with the second shift of men which is required in continuous running. The effect of shortening the running time of the engines is to increase the size of the engines and diminish the size of the battery. The article also contains an investigation of the effect of switching regulating cells in and out.

G. K.

An Experimental Study of the Alternating-Current Arc.

By A. BLONDEL.

(La Lumière Électrique, vol. xlii., 1891, pp. 551, *et seq.*)

This Paper contains an account of the investigation by stroboscopic methods adapted to photographic record, of the periodical variations in the electric arc, resulting from the alternations in current and potential for each complete phase of the generating dynamo. The mechanical arrangement of details, illustrated and fully described, consisted in fixing, on a prolongation of the arma-

ture shaft, a drum, on the surface of which could be fixed sensitised paper, and on this paper, limited by a sufficiently narrow slit, could be focussed any given portion of the electric arc; so that, when the dynamo was in motion, the arc of a lamp fed by its current would produce its own picture for each definite instant of time, and as the movement of the paper would be in continuous accord with the variation of the arc, any required exposure could be allowed.

The reproduction of the photographic result, with full details of the electric quantities governing each experiment, allow certain general conclusions to be drawn as to the behaviour of the arc under different external conditions, but owing to the actinic power not being a complete representation of the actual energy in the arc, it is not possible to calculate from the results, as fully as could be wished, the real efficiency of the alternate-current arc.

The following special points may be noted as the result of an examination of the plates; in some cases the extinction of the arc in each period may equal the actual time of existence, but the arc is then very unstable; while the addition of self-induction to the external circuit reduces the time of extinction, and thus increases the stability. The displacement of the phase due to lag is also clearly shown; the arc also increases slowly in breadth, and then collapses much more quickly, so that the form during a half phase is represented by an elongated pear-shaped figure.

The effect of a magnetic field in deflecting the arc alternately right and left is of course very clearly shown, but there are certain regular oscillations of a similar character, the cause of which remains unexplained. A slight deviation from the vertical position in photographs taken parallel to the direction of the arc, tend to show that the flow of carbon particles is from the positive to the negative, and with a velocity of the order of 160 metres per second. The stability of the arc depends in the highest degree on the characteristic curves of the arc and the dynamo, and it is necessary that these should cut one another at a proper angle, in order that the arc may regulate properly; in certain cases it is shown how an alteration in the voltage at the terminals of the machine, and the addition of resistance or self-induction may affect this question of regulation and stability.

This method of examination is also applicable to the continuous current arc, for investigating the causes of hissing and flaring; this is shown to be produced by any sudden change in either of the quantities of the product $E I$, though the product remain constant; but the photographic result in the two cases is quite different. The Author concludes that a directing solenoid of weak power has a favourable effect in preventing the hissing of a continuous current arc, but no useful action at all on the alternate; while, if in the former case the field due to the solenoid be increased, hissing will be then produced by it.

F. J.

The Brillié Electric Meter (Type, 1891). By F. GÉRALDY.

(La Lumière Électrique, vol. xlii., 1891, p. 465.)

This meter consists of an electro-dynamometer, the coils of which are in the main and shunt circuits; to the movable coil is rigidly fixed a copper disk, close to the surface of which are the poles of a system of magnets, with its axis of rotation in the same line as that of the dynamometer coil, and set in motion by a small electro-motor which is put into circuit by a contact actuated by the dynamometer. The action of the instrument is as follows: As soon as a current flows through the dynamometer coil, it deflects the coil and so closes the circuit of the electro-motor, which in its turn rotates the magnets in the opposite direction; the action of these magnets on the copper disk will at a certain speed bring the dynamometer back to zero, and thus open the circuit of the electro-motor; the contact arm on the dynamometer coil is arranged to throw resistances gradually out of circuit so as to increase the speed of the motor at larger deflections, but as this is effected by only three gradations, the actual balance between the motor and the dynamometer is the result of a series of intermittent impulses of the former. A numerical counter, connected by suitable gearing with the motor, indicates the quantity of electricity used in the circuit controlled by the meter, that consumed in the meter itself being somewhere between 0.2 and 0.5 per cent. of the total.

F. J.

On a Thermo-Electric Standard of Electromotive Force.

By HENRI BAGARD.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxiii., 1891, p. 849.)

The ordinary metallic thermo-electric couples labour under the disadvantage of having values extremely small, and at the same time variable, for different specimens of the same materials. The Author proposes, therefore, to adopt liquids which will afford elements of unvarying composition, and his researches have shown that with a mercurial amalgam of zinc, containing one-twentieth per cent. of the latter metal, and a solution of sulphate of zinc, saturated at freezing point, a thermo element can be constructed which is non-polarisable on closed circuit, and of which the electromotive force for the temperatures 0° and 100° Centigrade of the junctions is 0.1167 volt, with a variation not exceeding one-thousandth of that value. The process of formation of the element and form of mechanical construction are described in detail, and the formula for temperatures between 0° and 100° Centigrade is given as :

$$E' = 0.001077 t + 0.00000090 t^2.$$

If the quantity of zinc in the amalgam is less than that stated above, the element polarises; and if more, the element is then non-polarisable, and the electromotive force diminishes in some proportion to the extra quantity of zinc; but as a variation of one-fiftieth in the quantity of the latter causes a change in the electromotive force of only about one-hundredth per cent. of its total value, excessive precision in weighing the zinc is not in general required.

F. J.

Electro-Dynamometer for Three-phase Currents.

By Dr. F. ZICKERMANN.

(Elektrotechnische Zeitschrift, 1891, p. 509.)

In this article the Author gives a theory of the ordinary electro-dynamometer if used as a wattmeter for alternating currents, and also of a modification of this instrument for use on a three-phase current circuit. The starting-point for his theory is the well-known fact that the activity or work done per unit time in a simple alternating current circuit, is represented by the product of current, electromotive force, and the cosine of the lag between the two. If it were possible to obtain a wattmeter, the fine wire coil of which has absolutely no self-induction (time constant $\frac{L}{R} = T = 0$), then the instrument would indicate directly the true watts; but as this is not possible a correction must be introduced, depending on the time-constant of the wattmeter and also that of the circuit to be measured. Calling the latter $T_1 = \frac{L_1}{r}$, the correction by which the watts indicated by the wattmeter must be multiplied in order to obtain the true watts, is—

$$F = \frac{1 + (\omega T)^2}{1 + (\omega T)(\omega T_1)}, \text{ where } \omega = 2\pi \text{ times the frequency.}$$

If the wattmeter has a smaller time-constant (less self-induction in proportion to resistance) than the circuit to be measured, then the correcting factor F is less than unity. It is greater than unity if the time-constant of the instrument exceeds that of the circuit, as for instance, when the instrument is used to measure the power supplied to a bank of glow lamps.

In order to apply the correction it is of course essential to know the time-constants, and although that of the instrument can once for all be determined, that of the circuit would have to be determined specially in every case—a difficulty which the Author avoids by making simultaneous measurements of voltage E and current I , in the circuit under test. If W be the true, and w the apparent,

watts indicated by the instrument, he shows that the following relations exist—

$$W = w (1 - S),$$

where S is a new correcting factor given by the expression—

$$S = \pm \omega T \sqrt{\frac{(IE)^2}{1 + (\omega T)^2} - \omega^2}.$$

In order to determine whether the correction is to be taken + or -, the Author analyses this expression by introducing the different angles of lag, and finds that if

$$\sqrt{1 + (\omega T)^2} < \frac{IE}{w - S},$$

the correction must be deducted, whilst if

$$\sqrt{1 + (\omega T)^2} > \frac{IE}{w + S},$$

it must be added.

He next gives a method for finding the time-constant of the wattmeter without the use of any instruments usually employed in determining self-induction. The wattmeter is joined up to a glow-lamp circuit and two readings are taken, one with the fine wire coil directly connected to the mains, and the other with a known and inductionless resistance introduced into the circuit of the fine wire coil. If a_1 and a_2 are the readings of the wattmeter under these conditions, and R_1 and R_2 the corresponding resistances in the circuit containing its fine-wire coil, the coefficient of self-induction of the latter is

$$L = \frac{1}{\omega} \sqrt{\frac{R_1 + R_2 - \frac{a_1}{a_2} R_1}{\frac{a_1}{a_2} \frac{1}{R_1} - \frac{1}{R_1 + R_2}}}.$$

The Author then extends his investigation to a special kind of wattmeter intended for use with three-phase currents. He supposes that the distribution of current between the three wires is absolutely symmetrical, and that each wire conveys an equal amount of energy, conditions which he considers to be generally fulfilled in rotary field motors. The wattmeter constructed for this purpose has three coils, of which one is a thick wire coil of few turns placed in series with one of the three circuits, whilst the other two coils are of fine wire and contain a larger number of turns. They are wound side by side, and are connected as shunts between the line wire joined to the thick coil and the two other line wires respectively. The Author finds that the correction

required when using this instrument is of the same kind as with the ordinary alternating current wattmeter, but in the above formulas $IE \cos 30^\circ$ must be inserted instead of IE , and $2 \omega T$ instead of ωT . Numerical examples are given showing the magnitude of the correction necessary, and in one special case this reached as much as 70 per cent. of the observed watts.

G. K.

*Second Note on Measurements of Capacity and Self-Induction
Made on Overhead Lines.* By E. MASSIN.

(Annales Télégraphiques, 1891, p. 338.)

Two lines between Bordeaux and Pauillac were experimented on. One, $30\frac{1}{2}$ miles long, consisting of two iron wires 0·118 inch diameter, placed on the third and fourth rows, 1 foot $4\frac{1}{4}$ inches apart on poles 26 feet 3 inches high; the other $30\frac{1}{2}$ miles long, consisting of two copper wires 0·098 inch diameter, placed on the upper portion of poles the same height, the wires being 1 foot $4\frac{1}{4}$ inches apart.

The following Table summarises the Author's results, the figures given being the respective quantities per mile in each case :—

Description.	Insulation in Megohms.	Resistance in Ohms.	Capacity in Microfarads.	Self-Induction in Henrys.
Iron wire, No. 1	2·23	29·4	0·0166	..
" " No. 2	2·17	29·4	0·0151	..
" " Nos. 1 and 2 com- bined}	..	..	0·0111	0·0027
Copper wire, No. 1 . . .	5·0	8·86	{0·0153 ¹ 0·0148 ² }	..
" " No. 2	5·9	8·86	{0·0170 ¹ 0·0153 ² }	..
" " Nos. 1 and 2 combined}	..	..	{0·0116 ¹ 0·0105 ² }	0·0040

¹ Weather damp.² Weather drier.

C. H. W.

An Automatic Make-and-Break Switch. By MAX DE NANSOUTY.

(Le Génie Civil, vol. xx., 1892, p. 247. 1 Fig.)

The Author describes a type of automatic make-and-break switch, which has been designed by Mr. Charles Féry, and made by Ducretet, of Paris. The object of the switch is to prevent the current from a battery of accumulators returning to the dynamo which is used for charging when the speed of the latter becomes less through any cause. It consists of a straight lever balanced near the centre, and carrying at the centre a plate which dips into the mercury cup forming one pole of the switch, and also of a similar plate at one end of the lever dipping into a second mercury cup forming the other pole of the switch. The other end of the lever passes through the interior of a bobbin wound with wire, a second bobbin above the latter is provided with a soft-iron core to which are attached two vertical pole-pieces reaching to within a short distance of the movable lever. The winding of the top bobbin is either in the field magnet circuit of the dynamo or is a shunt on the terminals of the dynamo. When the dynamo is running at such a speed as to produce an electromotive force high enough to charge the battery, a current will flow through the top bobbin polarising the polar extensions; the latter will attract one end of the balanced lever, the plate at the other end of the lever will descend into the mercury cup, and contact will be made. The voltage will then be lowered to some extent, and the lever is held in position by the second bobbin, which has a winding of higher resistance than the first. In case the speed of the dynamo should vary from any reason sufficiently to lower the electromotive force below that required for charging the battery, the current in the lower bobbin becomes too feeble to hold the lever up; connection is then broken by means of a spiral spring, which draws the end plate out of the mercury cup.

The advantages claimed for this type of automatic switch over the electro-magnet gravity switch which is in ordinary use are that the current is broken when it is very feeble, and that owing to the arrangement of the bobbins repulsion of the lever would take place, so that in case the spiral spring were out of order the circuit would still be broken. The Author states that with this instrument the current can be broken when the electromotive force falls very slightly below the required pressure. The mercury used must be chemically pure, and it is an advantage to cover its surface with a little glycerine.

E. R. D.

The Central Electric-Light Station at Elberfeld.

By C. DIHLMANN.

(Elektrotechnische Zeitschrift, 1891, p. 646.)

In this article the Author gives an account of the commercial results attained in the working of this station, which has been in operation since the beginning of 1888. The supply is direct on the three-wire system without batteries. The loss in the feeders is 5 per cent., and in the mains $1\frac{1}{2}$ per cent., calculated for 10,000 55-watt lamps burning simultaneously. The number of lamps wired during the first year (1888) was only 3,822, and the station was run only during the evening up to midnight, or 1 ampere. The capital outlay incurred then was £40,000; the working expenses about £1,935, and the receipts for 2,555,862 lamp hours (140,000 Board of Trade units) about £4,820, or $8\frac{1}{4}d.$ per unit. In 1889 the number of lamps connected had increased to 5,164, and the capital expenditure had been increased by £2,500. The receipts for 3,337,824 lamp hours were £6,311, and the working expenses were £2,325. In 1890 there were 6,893 lamps connected yielding 4,161,002 lamp hours (230,000 Board of Trade units), and £7,950, whilst the capital outlay had again been increased by £2,500, and the working expenses were £2,735. The Author appends extensive tables, in which the various items of expenditure are set out in detail. For 1890, when 230,000 units were sold, the cost of fuel was £663; petty stores £263, and maintenance and repairs £418. The tables are brought down to August, 1891.

G. K.

The Electric Lighting of Paris. By MAX DE NANSOUTY.

(Le Génie Civil, vol. xx., 1891, p. 35. 1 Plate, 2 Figs.)

The electric-lighting of Paris has been taken up by four companies, which obtained concessions from the Municipal Council. These companies are Messrs. Mildé, Clerc and Co., who have a station in the Faubourg-Montmartre; the Transmission of Power Company have a small station in Rue de Bondy, which supplies several theatres, and has been increased greatly since its opening. This station contains four compound engines of the vertical type, built by Weyher and Richemond; each is of 150 HP., and runs 160 revolutions per minute; these drive four Desroziers dynamos running at a speed of 300 revolutions per minute. The same company have since laid down three more central stations: in the Rue des Filles-Dieu, at the Gare du Nord, and in the Boulevard de la Villette; these are supplied with the same class of engines which drive direct by means of the Raffard

elastic coupling eleven Desroziers dynamos, which rotate at a speed of 160 revolutions. The Edison Company acquired the right to light the centre of the Faubourg-Monmartre, and they have built a station in the Avenue Trudaine, while the fourth company, known as the Popp Compressed Air Company, have built a station on the Boulevard Richard-Lenoir. The latter two stations are worked on the same lines. Direct driving of the dynamos is used, and the units of power are larger than were formerly employed. Some of the steam-engines are of 300 HP., running at 135 revolutions; each driving by an elastic coupling one dynamo on each side, each of the dynamos having half the output of the engines. The Author then proceeds to describe the work of the Popp Company, and states that while the other companies supply current to the network direct from the machines in the central station, the Popp Company employs sub-stations fitted with accumulators which supply the network. The network has no connection with the charging mains to the sub-stations, so that considerable latitude is obtained in the potential which may be employed. At certain times the battery charging current has a potential of 2,400 volts. As the batteries always require the same amount of current the central station units may be kept working at full load; the high potential allows small mains to be used. The districts supplied by this company should be fed by four central stations of equal power. That, however, on the Boulevard Richard-Lenoir supplies the greater part of the energy, while the others on the Retiro, near the Madeleine, and Bourse du Commerce are smaller. Each station feeds a closed loop-main, so that four main circuits are formed; in these circuits twenty-five battery stations are placed, and in order to avoid accident three of the sub-stations are connected to two circuits. By means of switches two circuits may be connected into one, and diagrams are given in the Paper of the arrangement. The potential in one of the circuits may be from 400 to 2,400 volts according to the number of batteries being charged. The current is constant at 250 amperes, and each of the dynamos develops 400 volts; they may be coupled in series varying from 2 to 6. Each of the batteries consists of sixty-five cells, and each sub-station contains two such batteries.

The station in the Boulevard Richard-Lenoir contains three units of 300 HP. each, and a fourth unit is kept ready in case of accident. It contains, therefore, eight multipolar dynamos of the Desroziers type, four Weyher and Richemond triple-expansion engines, and four Babcock and Wilcox boilers with the subsidiary plant.

In ordinary working two boilers are sufficient for the supply of steam; the third is kept lighted during the hours of greatest load. The machine-room is 69 feet long by 39 feet 6 inches wide, and from this area a constant supply of 800,000 watts is furnished to the district. The Author gives a detailed description of the engines.

The Raffard coupling consists of a fly-wheel on the engine,

which carries a number of pins arranged in a circle. The dynamo shaft carries a disk bearing a second set of pins placed on a circle smaller than the other. The two series of pins are connected together by india-rubber links. The driving is stated to be silent and steady, and the dynamo may be perfectly insulated from the engine. The principal features of the dynamos are absence of iron in the armature, perfect ventilation, and the lightness of the rotating parts. The insulation is an important question, as when six of the dynamos are coupled in series the total electromotive force is 2,400 volts. The brushes are doubly insulated, and only four, placed in two planes diametrically opposite each other, are used although the machines are multipolar. The insulation of the armature coils was at first three megohms; the Author states that it now varies between 200 to 250 megohms. The efficiency of the machines is 93 per cent. Separate exciters are used, which are driven by belts from the fly-wheels of the engines. Eight switch-boards are used, and each is placed in series with the outside circuit. It is possible to short-circuit the outside main when the corresponding dynamo is at rest, and to introduce the dynamo into the circuit without interrupting the charge of the sub-stations; the electromotive force is controlled by a rheostat in the circuit. Further particulars are given respecting the instruments used. The plant is kept working every day from midnight till 10 P.M. As a rule one battery in each station is being charged while the other feeds the circuit, but from 6 P.M. to midnight the two batteries are often working together.

E. R. D.

On the Intensity and Quality of Telephonic Effects.

By E. MERCADIER.

(Annales Télégraphiques, 1891, p. 289. 7 Figs.)

The intensity of action of a telephone depends on three things : (i.) the thickness of the diaphragm; (ii.) its diameter; and (iii.) the strength of the magnetic field in which it is placed. The Author has investigated the effect of varying¹ these three factors separately, and has shown that for a given field and diameter, there exists a certain thickness which gives maximum intensity. When the diameter is varied, two results ensue, the greater the diameter, the more flexible the diaphragm; but since the action of the field is confined to a small space, the idle proportion of the diaphragm is increased, so adding to its inertia. With a stronger field the active part is increased, and hence to each field-strength there corresponds a diameter of dia-

¹ Comptes Rendus de l'Académie des Sciences, 1885, 1887, 1889. Annales Télégraphiques, 1886, 1889.

phragm giving the best results. The advantage that would presumably arise from increasing the strength of field is largely discounted by the iron of the diaphragm becoming saturated; any increase after this takes place is not only useless, but actually deleterious, since the lines of force are stiffer and resist more the mechanical vibrations of the diaphragm. The figures in the following Table are given to show the relations between the three factors in several well known instruments.

Instrument.	Numbers Proportional to Strength of Field.	Thickness of Diaphragm in Millimetres.	Diameter of Diaphragm of use for Induction in Millimetres.
Gower	4.44	0.572	90
Pollard	3.365	0.71	100
D'Arsonval (large type)	2.84	0.626	90
„ (small „)	2.11	0.307	56
Ader	1.16	0.327	40
Aubry	0.90	0.26	56
Ochorowickz	0.72	0.294	60
Colson	0.635	0.446	90
“Bitelephone” (see page 514)	0.155	0.13	26

The Author considers that the form of the magnet should be such that the lines of force are at right angles to the direction of the wire of the coils. An advantage also results from mounting the magnet and soft iron core so that they are free to vibrate to a small extent.

The clearness of the speech transmitted is even more important than its loudness. The nasal twang often noticed is due to the fundamental and harmonic vibrations of the disk being superposed on the free movements of the molecules. Their presence is favoured by the intensity of the vibration which is thus gained at the expense of clearness. In order to avoid this, it is only necessary to employ a diaphragm having its fundamental note beyond the ordinary range of the human voice. Extreme examples of such are plates 10 centimetres (3.94 inches) diameter, and 1 millimetre (0.039 inch) thick, or 3 centimetres (1.18 inch) diameter, and 0.1 millimetre (0.0039 inch) thick.

Another defect in the majority of telephones is the weakening of certain letters and sounds, and the Author ascribes this to the form taken by the mouth in emitting them, being such that small force is exerted. This fault is much less marked when the nasal twang which tends to exaggerate certain other letters is suppressed.

A third action prejudicial to clearness is caused by superposed vibrations other than those mentioned. One set has a rasping character, and is due, in the Author's opinion, to variation in shape of the lines of force in the iron, it being scarcely perceptible in telephones of equal intensity, having diaphragms of non-magnetic materials. The effect disappears with iron diaphragms

if they have a high fundamental note. Another set of vibrations is loud and of low pitch, and is caused by the air enclosed in the instrument; they can be easily suppressed by filling most of the space with felt and so reducing the quantity of air.

The Author proceeds to point out that although a telephone can be used either as transmitter or receiver, the same instrument is not equally suited to both purposes, since the force at work is many times greater in the former case than in the latter. He then describes the application of his researches to the production of a receiver to which he has given the name of "bitelephone." Its characteristics are extremely small magnets, and therefore small coils. The weight of this part of the instrument is thus reduced to about one-fifth of that of ordinary receivers. Since the diaphragm need only be thick enough to just absorb all the lines of force of the magnet, it is very thin, and its diameter also is small in order to obtain a high fundamental note. The parts are mounted in an ebonite box, and the instrument weighs only about $1\frac{3}{4}$ oz., instead of about 14 oz., the usual amount. Two of these small receivers are carried by a light U-shaped spring of 2 millimetres (0.079 inch) steel wire, and rest on the ears, the spring passing under the chin of the user. The spring further serves to connect the coils electrically, and is magnetized in order to keep up the strength of the field. Two conical pieces of india-rubber tubing are slipped over the covers, and pass into the ears, serving to exclude extraneous noises, and giving a soft bearing against the ears. Particulars of the instrument are shown in the Table already given.

The Author states that the bitelephone has been tried with different kinds of transmitter on underground lines over 40 miles long, on a telephone line nearly 500 miles in length, and on the London-Paris line; it was found that while the loudness was comparable with that of ordinary receivers, the clearness was greater.

The Author concludes by enumerating various applications of the instrument, and gives directions for fitting it to transmitters either by itself or in conjunction with the ordinary receivers.

C. H. W.

A Divided Telephone Switchboard. By — MANDROUX.

(Annales Télégraphiques, 1891, p. 312. 15 Figs.)

In this article the Author gives the details of the practical working out of his system.¹

The apparatus is mounted on vertical boards, and the arrangements are such that the operators can work easily either sitting or

¹ Minutes of Proceedings Inst. C.E., vol. cvi., p. 420.

standing; a shelf about a foot wide runs along the base of the switches at a convenient height for writing, and serves as a support for instruments, etc.

The following is a brief account of the more noteworthy parts:—

(i) *Entrance boards*.—Each of these carries five hundred indicators and buttons and six calling-keys, and is formed of a rectangular mahogany or walnut frame 2 feet high and 3 feet 8 inches wide. The indicators have a resistance of about 200 ohms, and the chief point of novelty consists in the shutter disclosing a ringing button when it falls. The buttons, mounted behind the shutters, when pressed make contact with, and put to earth, the frames of the indicators, these frames being connected to the corresponding indicators on the sectional board. The calling keys make a double contact when pressed, part of the current dropping a subscriber's indicator on the sectional board, and part the "warning" indicator on the same board. Each calling key is provided with a polarised indicator for the sectional operator to signal back. A permanent magnet, bent at right-angles near one end, carries at the other two soft-iron cores, between which hangs an armature so balanced that it remains indifferently against either according to the direction of the last current that passed through coils wound on the soft-iron cores. To the armature is fixed a light arm with a thin metal rectangle at the end that covers the word "free" or "engaged" according to its position.

(ii) *Sectional boards*.—Each of these is a vertical frame about 4 feet wide and from 22 inches to 28 inches high according to the size of the exchange. It is divided horizontally into three parts; the upper carries five hundred line-connectors (corresponding to the jacks of ordinary boards) each with an indicator behind it; the middle portion twelve ring-off devices and the "warning" indicator, while the lower forms the support for the cross-connecting jacks. Each line-connector comprises three brass blocks mounted on ebonite and insulated from one another; a hole is drilled through two of them and through the ebonite between; in a groove at the side of each is fitted a spring which traverses the hole near its side, so that it is pressed outwards when a plug is inserted. The springs ensure good contact between the plug and blocks, and one of them in addition rests normally on the third block from which it is raised by the insertion of the plug. All contacts are platinum tipped. The points aimed at in the construction of the plugs are certainty of contact, ease of manipulation, and solidity of the parts. Each comprises two cones on the same axis insulated from one another, the hinder one having a shoulder to prevent the plug entering too far; contact is made by them respectively with the springs in the line-connectors. The connection between the cones and the conductors in the flexible cord is made by means of the two halves of a box insulated from one another by an ivory disk, and capable of revolving with it round a central pin. The sides of the box respectively rub against parts of the plug in contact with the cones, and a conductor is screwed

to each half, so that the cord does not partake of any twisting motion that may be given to the plug, and is thus relieved from the stress that would otherwise ensue. In front of each line-connector, blocking its entrance, is a shutter pivoted at one end, and held in position by an arm carried by the indicator. When an entrance-board operator sends a current, the shutter is released and discloses the line-connector. The ring-off devices comprise each an indicator, two plugs and cords, a galvanometer, and a double key. In front of the indicator, and blocked by its shutter, is a contrivance similar to the line-connectors, with only two blocks that are joined together when a plug is inserted. The galvanometer is in the ringing circuit on the side connected to the subscriber asked for and deflects if the line is not engaged. The index carried by the needle is a flat brass plate, horizontal when no current passes, and tipped to one side or the other according to the direction of the current when it flows. The double key is so arranged that the subscribers can be rung separately or both at once. The "warning" indicator is similar to those on the entrance-board, the button disclosed by it serving to work the polarised indicator on that board. The cross-connecting jacks at the lower part of the board are each connected to a flexible cord on the central board, and each has a button controlling an indicator on the latter.

(iii) *Central boards*.—These are each about 4 feet wide, and comprise three portions, one vertical and two inclined. The upper one of these latter is about 1 foot 8 inches long, and is perforated with four hundred and eighty holes (in a twenty thousand line exchange), through which pass weighted cords attached to plugs. The other is about 1 foot long, and carries five hundred line-connectors similar to the cross-connecting jacks. The vertical portion is 10 inches high, and on it are mounted five hundred indicators worked by the buttons of the cross-connecting jacks on the corresponding sectional board; they serve to show which plug is to be connected.

The Author concludes with a few remarks on the general arrangement of the wires in the exchange, and insists on the necessity for a good light on the boards. He estimates that for an exchange of ten thousand subscribers, a room about 66 yards long and 11 yards wide would suffice, but points out that on account of the different sections of the switchboard being independent they may be in separate rooms or even on different floors.

C. H. W.

On the Fitting of Telephonic Stations. By E. MERCADIER.

(Annales Télégraphiques, 1891, p. 385. 7 Figs.)

This is a discussion as to the best way of fitting the Author's Bitelephone¹ to existing instruments. The Author considers the case in which one of the two ordinary receivers is replaced by it. The bitelephone has a resistance of about 300 ohms, while that of the ordinary receiver is stated to be 200 ohms, and of the secondary of the induction coil, 200 ohms also. For urban communication the total resistance in circuit of the two stations, 1,400 ohms, is not excessive; but for communication between two towns, or for long distance telephony, it is necessary to reduce it. In the former case, the Author employs a short-circuiting key to cut out the ordinary receiver at each end, thus reducing the resistance to 1,000 ohms. For long distance speaking, in addition to this key a two-way switch is provided; in one position, that of transmitting, three-quarters of the resistance of the bitelephone is cut out, there being a sufficient number of turns left in circuit to enable the other subscriber to attract the attention of the one speaking. In the other position, that of receiving, the induction coil is cut out, leaving only the bitelephone in circuit. The total resistance is thus brought down to 575 ohms.

The ordinary receiver is retained apparently because it is more convenient for asking for the number required. The switch presents less difficulty on account of the speaker having both hands free.

The Author points out that the long distance method can be used in all cases if extra loudness be required, as in the case of people rather deaf.

The advantage of the bitelephone for exchange operators is adverted to, and when used for this purpose on multiple boards, an earth connection is made at the intermediate point in the coils for use in trying whether a line is engaged.

C. H. W.

High-Speed Electric Railways. By C. ZIPERNOWSKY.

(Elektrotechnische Zeitschrift, 1891, p. 516.)

This is a Paper read at the Electrical Congress, Frankfort, in which the Author gave a detailed account concerning the design of a railway line between Vienna and Budapest, intended for very high speed. The practical limit to speed is given by the ability of the wheels to withstand centrifugal force, and is stated by the

¹ *Ante*, p. 514.

Author to be about 155 miles per hour. The Author considers the train system as unsuitable for such a speed, both on account of technical and financial considerations, and he prefers the tramway system, or a succession of independent locomotive cars which should be dispatched at intervals of not less than ten minutes, each car to seat about 40 passengers, so that during the busy hours of the day some 200 passengers per hour could be carried. To provide the power, two electric control stations would be required, each about 31 miles from the terminus, and the currents would be conveyed along the line at a pressure of 10,000 volts, and transformed down at suitable intervals for distribution amongst the running cars. The following particulars relate to a car which has been designed at the works of Messrs. Ganz & Co., Budapest. Extreme length 148 feet, width 7 feet, height 7 feet 3 inches. The ends are cigar-shaped to reduce air-resistance, and are only accessible to the guards. The centre part of the car contains accommodation for 20 passengers and a moderate quantity of luggage and mails. The framework of the car rests on two bogey trucks, which can swivel through an angle corresponding to curves down to 1,100 yards radius. On each of the four axles is mounted the armature of an electro-motor, and the speed will reach 600 revolutions per minute. The wheels have double flanges, and the pressure on each journal is about $7\frac{1}{2}$ tons. The total weight of the car is 60 tons.

The current is collected by contact wheels from a pair of conductors placed parallel with and between the rails. A Westinghouse air brake is provided, and the air under pressure is stored in two steel tubes 4 inches diameter and 100 feet long. The air can be replenished by a pump either driven by hand or by an electro-motor.

Where the line is level the curves should not have a less radius than 3,300 yards, and on grades up to 1 in 100 the radius of curves may be reduced to 1,100, as the speed will then be reduced to 120 miles per hour. The rails are Vignoles type, 7 inches high and weigh 100 lbs. per yard. The sleepers are of cast steel placed 3 feet 3 inches apart in concrete.

Dealing with the power required for propulsion, the Author finds that his car will require 250 HP. to overcome the air-resistance when running at a speed of 120 miles per hour. The power required to mount a grade of 1 in 100 at the same speed is 450 HP., and adding 100 HP. for other losses, there results a total of 800 HP. per car as a maximum. This power would be supplied by a current of 600 amperes at 1,000 volts pressure.

G. K.

*Report on Electric Street-Railways for the City of Winnipeg.*¹

By H. N. RUTTAN, M. Inst. C.E.

The Author states that this Report has been compiled from information obtained during visits to Minneapolis, St. Paul, Dubuque, Chicago, Washington, Philadelphia, New York, Boston, Lynn, Montreal, Ottawa, and Toronto. His observations were directed chiefly to the "overhead trolley" and "storage battery" systems, these being most suitable for Winnipeg. As city engineer to the latter town, the Author collected numerous particulars as to the cost of construction and maintenance of both the systems, in order to enable the municipal authorities to form a correct opinion of the advantages of each of the systems. It appears that in Minneapolis the overhead system is employed, and poles are placed in the centre of the street between the tracks, which are from $3\frac{1}{2}$ to 4 feet apart. This arrangement has the disadvantage that in narrow streets the vehicular traffic is necessarily thrown to the sides of the street, as the centre cannot be used on account of the poles. In Boston the wiring is done from the sides of the streets, even in the case of long spans, and there the overhead system appears much less objectionable. There is no good reason why telegraph and telephone poles, where in suitable positions, should not be used to support the cross-wires of the overhead system, and they are so used in Ottawa.

Where streets are parallel and not very far apart, the "loop" system of tracks has many advantages. Single tracks only are necessary, the loops being interwoven like the links of a chain, and the cars running in one direction on one link and in the opposite direction on the next, thus giving street-car connection in both directions to within, at the most, one block of every street. This system is largely used in Philadelphia, and has, in the Author's opinion, many advantages over the double track system. The Author then enters into details of track construction, giving particulars as to the weight of rail, paving, and tie rods. He believes that the use of chairs is objectionable, and that a girder rail of the flange groove section has the disadvantage of causing the wheel flanges to wear on the inside, and in a cold climate the grooves are not easily kept clear of ice and snow.

In Dubuque the Street Railway Company of that town placed a trial car of the Electro-Dynamic Company on their line in August, 1890. At the date of the Author's visit, 25th of May, 1891, four of these "Edco" cars were being used, and others got ready. It was expected that fifteen cars would be in use by the winter, 1891-92, and the storage battery system seems to give satisfaction. The Author then enters into particulars as to the system.

It appears that the cars are 14 feet long, and carry twenty-two

¹ The original is in the Library of the Inst. C.E.

people; they are each fitted with two 15-HP. motors. Each car is fitted with a set of eighty cells, and during their use a similar set is being charged; two minutes is allowed for changing the batteries. Each battery is used for three hours, in which time the car runs 21 miles. The electromotive force of batteries coming in is 160 volts, and on going out 175 volts. The time necessary for charging is two hours.

In Washington two Edco storage-battery cars have been running for about four months on the lines of the Washington Street Railway Company, and six more similar cars are on order. It appears that a guarantee for three years has been obtained that the operation of these cars will not exceed in cost that of the overhead system in the same place. In this town the batteries are charged from the wires of the overhead system, a suitable resistance being inserted in the circuit. In Washington both the overhead and storage systems are used by the same company, storage being employed in streets where overhead wires are prohibited.

In New York there were no electric railways of any kind at the date of the Report, July 4th, 1891. In Boston the only electric railway is that of the West End Street Railway Company, upon which the Thomson-Houston overhead system is employed. The company is gradually changing from horses to electricity, and the advantages appear to be the greater speed attained by the cars and the greater cleanliness due to the absence of horses. The Author gives a Table showing the number of cars and mileage of this railway for each month since the cars were first used.

It appears that in February, 1889, nine cars were in use, making a total mileage of 15,186, whereas in July, 1891, over three hundred motor cars were in use. In March of the same year, a snowfall of 18 inches in depth occurred in Boston, and through this the cars worked satisfactorily. Data are then given as to the value of street railway franchises, and Tables are given which have been taken from the Report of the city engineer of Toronto, with respect to the profits obtained by the municipality.

The Author proceeds to compare the overhead and storage battery systems, and states that his remarks are intended to apply to systems having from 10 to 20 miles of track, using from fifteen to forty cars, and having no grades exceeding 4 in 100; operating in localities where snowfalls are not excessive.

1st. The cost for the two systems appears to be about the same; the engine-power for the storage system is the same as for the overhead, though it is probable that less power will be necessary for the storage system in future.

2nd. The maintenance of the storage batteries is stated by two companies to be 40 per cent. per annum on their prime cost, though two other companies guarantee that it will not exceed 10 or 15 per cent.

3rd. The power required on the overhead system is very variable, the engine-load may change in a few moments from 50 to 100 HP.; it is therefore necessary to keep full steam-pressure,

and the coal-consumption must, therefore, be always at its maximum. On the other hand, the storage cars are independent units; the engines at the central station may, therefore, be run at a constant rate, developing the average power to move the cars on the line. Considering the electrical efficiency of the storage battery to be 80 per cent., and of the overhead wire 90 per cent., the following Table shows the difference of power required at the central station:—

	Storage.	Overhead.
Average electrical HP. required at car-motors . . .	150	150
Maximum in storage-battery and overhead wire . .	150	300
Loss in batteries and overhead wires when engines are working at maximum	87.5	33
Total E.H.P. required	187.50	333

The Author concludes by stating that a road which is not too long and upon which there is heavy traffic, affords the best opportunity for economically working the overhead system; and a straggling road with a comparatively light traffic, affords the most favourable conditions for the storage system. The town of Winnipeg at present approaches more nearly the latter condition. He therefore advises that the storage-battery system should be used, and remarks that the overhead system has probably reached its maximum efficiency, while the storage-battery system has not yet done so.

E. R. D.

Electric Cranes, with a Special Reference to one in use at the Baldwin Locomotive Works. By C. J. BATES.

(The Railroad Gazette, New York, 1892, p. 73.)

The Author describes a "100-ton" (i.e., 200,000 lbs.) crane built for the Baldwin Locomotive Works by W. Sellers & Co., of Philadelphia. The crane consists of a rolling bridge of two parallel girders of 74 feet 8 inches span, and 7 feet deep out to out, placed 9 feet 3 inches apart, and carried by four 5-foot wheels, with double-flanged steel tires, the wheel-base being 14 feet, and the rails weighing 360 lbs. per yard, and carrying a rack of $2\frac{1}{2}$ pitch and 4 inches face in which work the travelling gear-wheels. As the crane has to lift a locomotive by both ends, there are two hoisting-trolleys, which run on rails carried by the lower flanges of the main girders, and each trolley is in itself a complete hoisting machine. The source of power is a dynamo, the terminals of which are connected to two $\frac{7}{8}$ -inch rods of copper, supported on yellow pine strips and glass-insulated. On the rods run a pair of small four-wheeled trolleys of the Wheeler type for picking up current. Each trolley is coupled to a 40-HP. United States Electric Light Co.'s motor of constant speed, shunt-wound for a 220-volt current. Their speed is 500 revolutions per minute.

They stand on the top of the bridge over the operator's platform, and are belted to the gearing below, which operates the hoisting-trolleys, one set of gearing being on each side of the bridge. The two systems are connected by a belt across the bridge, and, so far, there has been no burning of either motor, as might occur if one motor overran and turned the slower one into a dynamo. The systems of gearing, made up of various clutches, &c., transmit power to the hoisting-trolleys through three square shafts to each trolley, and on each trolley, for hoisting or lowering, there are four speeds, viz., 5, 10, 20 and 40 feet per minute, and two traversing speeds, 50 and 100 feet per minute. A special clutch holds the weight, and prevents a "run" when changing speed or direction. The hoisting-block has two sheaves, and the chains are also in two parts, and the winding of the drums runs towards the middle, so that an object is lifted vertically. Each trolley will lift 100,000 lbs.

On one trolley there is a small 5-HP. Wenstrom motor and hoisting-gear for small weights. There are nine levers to be worked by the operator, and they are arranged to be moved in the direction of motion intended to be given to the loads, as far as practicable.

The Paper is illustrated.

W. H. B.

Overhead Cranes Worked by Electricity. By F. DESQUIENS.

(Le Génie Civil, vol. xix., 1891, p. 324.)

The Author refers to the methods in ordinary use for working overhead cranes, and states that the use of electricity obviates much inconvenience, and the electrical apparatus can be easily applied to existing steam cranes. Messrs. Schneider & Co. have recently applied electricity for working a 60-ton overhead crane in their artillery workshops. The crane serves a shop 49 feet wide and 328 feet long. When driven by means of a cable it could only lift 35 tons continuously at a speed of 2 feet per minute, and with this load could only travel at a rate of 49 feet per minute. It was found that when the load exceeded 35 to 40 tons that the cable slipped upon the guide pulleys, and was rapidly burned away; no cable lasted longer than from eight to ten months. Latterly it was proposed to use the crane over a length of 230 feet more, making a total of 558 feet. This could not be effected by means of the cable, nor could the maximum power of the crane be used. Very satisfactory results were obtained upon a 15-ton crane by the adoption of a Ganz motor built at Creusot, and the same system was applied to the 60-ton crane.

The details are as follows:—A continuous-current Ganz motor

developing 45,000 watts is fixed upon the framework of the crane on the opposite side to the controlling gear; this drives the shaft, upon which are fixed the gear wheels, by a belt of the same length as the width of the crane; the current is brought to the motor by two bare cables 0.47 inch diameter fixed at the two ends of the shop, and carried upon porcelain pulleys 33 feet apart; the current is taken off by two brushes fixed upon the crane. All the accessory apparatus, such as switches, rheostats, amperemeter, and voltmeter, are placed under the control of the driver. The current is produced by a dynamo of the same power as the motor, and the current is also used for a 15-ton crane and for a carpenter's shop in which machinery is driven by motors. With this arrangement the large crane easily lifts 40 tons at a speed of 7.2 feet per minute; it travels at a speed of 89 feet per minute, so that only six minutes are needed for travelling the whole length of the shop.

The electromotive force of the dynamos is constant at 220 volts, and the variation of speed of the motor between no load and full load does not exceed 5 per cent.; no special precaution is needed in raising the load suddenly; a special safety apparatus has been arranged. Messrs. Schneider are now designing a crane to lift 150 tons worked in the same manner.

E. R. D.

An Electric Elevator. By F. DESQUIENS.

(Le Génie Civil, vol. xx., 1891, p. 25. 1 Fig.)

The Author states that a new electric elevator has been brought out by Mr. J. A. Amiot, and was exhibited at the Palais de l'Industrie. Much space is required for the ordinary types of hydraulic elevators, and this is not always available in the case of old buildings. No space is required for the electric elevator in such a position as is needed for the ordinary type of lift. It consists of a carriage in which a seat is arranged, and so constructed as to run easily upon a pair of rails fixed to the inside of the balustrade of the staircase. The base of the carriage is only a short distance above the steps, and as it is not closed in like a hoist a person can easily step out at any position. The carriage is drawn up by means of a steel rope, guided by suitable rollers, and worked by an electric windlass. A special brake is attached to the carriage so that in case of fracture of the cable the carriage would be brought to rest in a distance of about 10 inches. The width occupied by the carriage being only 12 inches, but little obstruction is offered to persons ascending and descending on foot. The current is usually taken from the ordinary electric mains; but gas, or compressed-air motors could, of course, be used. When electricity is obtained from the street mains, the price per ascent

per storey is stated to be 0·03*d*. The total cost of installation is given as £48 to £60 for the first floor, and a sum of from £16 to £20 for each succeeding floor. No attendant is required, as the person making the ascent works the switch, and an alternate arrangement is attached by which the carriage is brought to rest at the end of its course.

E. R. D.

On the Most Important International Units of Mass.

By CARL AUGUST PORGES.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens. Wien, 1891, p. 489.)

The Author premises that his object is to treat this subject in a way that may be useful to practical men. The adoption of units of measurements which are not related to each other in some simple way, involves the performance of laborious calculations and the use of constants which it is frequently hard to remember. More especially is this difficulty felt by electricians, for although the units they employ are directly connected with the absolute system, yet these have to be considered in relation to the arbitrary units of the Mechanical Engineer.

After dealing with the theory of the subject, and describing at some length what is meant by the dimensions of a unit, the Author proceeds to a detailed enunciation of the C. G. S. system, with especial reference to the problems that arise in connection with heat-engines. A continuation of the Paper is promised.

G. J. B.

The Decimal Division of the Degree. By K. MIALOVICH.

(Berg- und Hüttenmannisches Jahrbuch der k. k. Bergakademien, vol. xxxix., p. 323.)

If, in the old division of the circle into 360°, the unit is subdivided into 100 × 100, or 10,000 equal parts, it is easy to convert any angle expressed in minutes and seconds into a decimal fraction of a degree by the use of the following figures:—

	°	"	"	
For	$\frac{1}{10}$	$= \frac{3.600}{10}$	$= 360$	= 6 minutes,
	$\frac{1}{100}$	$= \frac{3.600}{100}$	=	36 seconds,
	$\frac{1}{1.000}$	$= \frac{3.600}{1.000}$	=	3·6 seconds,
	$\frac{1}{10.000}$	$= \frac{3.600}{10.000}$	=	0·36 second.

Thus, the conversion of an angle of $25^{\circ} 53' 42''$ to its decimal equivalent would be effected in the following manner:—

$$\begin{aligned}
 25^{\circ} &= 25^{\circ} \\
 53' &= \frac{53}{60} = 0.8^{\circ} + 5' = 0.8^{\circ} + 300'' \\
 300'' + 42'' &= \frac{342}{60} = 0.09^{\circ} + 18'' \\
 18'' &= \frac{18}{3600} = 0.005^{\circ}, \\
 \text{hence } 25^{\circ} 53' 42'' &= 28.8950^{\circ}.
 \end{aligned}$$

For direct decimal readings on this system, the theodolite, especially if constructed for mine surveys, must be divided differently to the graduation now in vogue. This would, however, not present any difficulty to the instrument maker. Instead of the usual $\frac{1}{3}^{\circ}$ division on the limb, a division into $\frac{1}{4}^{\circ}$ would be required, so that with a vernier with divisions of $\frac{2}{3}''$, the least reading would be 0.01° , or with a bisected vernier graduation 0.005° , or $18''$. Thus, reading would be possible to an accuracy of $12''$ more than with the ordinary instrument. The advantages of this method of expressing angles will be obvious. For logarithmic calculations the Author has drawn up a Table of logarithmic sines and cosines, from 0° to 90° , which accompanies his Paper. Having thoroughly tested the system, he is convinced that its adoption is conducive of accuracy and of rapidity in surveying work.

B. H. B.

Explosives and Ordnance Material. By STEPHEN H. EMMENS.

(Proceedings of the United States Naval Institute, 1891, p. 355.)

The explosion of what is known as dynamite No. 1, containing 75 per cent. of nitro-glycerine, is found to be more effective than that of pure nitro-glycerine itself. The Author explains this apparent anomaly by what he calls a ballistic theory of explosives.

He calculates the pressure which would be exerted upon the walls of a shell containing the explosive, which pressure represents the aggregate of the impacts of the gaseous molecules, and is directly proportional to the *vis-viva* of the mean molecular movements. But since *vis-viva* is composed of two factors, mass and velocity, the determination of gaseous pressure alone fails to indicate the character of the blows by which it is produced. It tells nothing as to whether the walls of the containing vessel have to withstand the shock of heavy molecules moving with comparative slowness or of light molecules moving at relatively high velocity. The Author shows that although the pressure upon the walls of the shell is greater in the case of nitro-glycerine, both the intensity and velocity of the blows delivered by the dynamite molecules are greater than those of the

nitro-glycerine, and the ballistic effect obtained in this manner by calculation is in accordance with that found by experiment.

Proceeding from the consideration of the explosives and the gases they produce to a study of the effect of the molecular impacts upon crusher-gauges, gun-walls, etc., he finds the ballistic theory still holding good and of service in the solution of many practical problems.

Under a very rapid pressure the shortening of a crusher-gauge is twice as great as in the case of a comparatively slow pressure, and the governing feature of the action is said to be the ratio that exists in any particular case between the total duration of the pressure from zero to a maximum and its duration while at a maximum.

The opposition offered by solid bodies to change of molecular structure is analogous to the energy of gaseous bodies, and may be divided into a resistance-factor and a time-factor, which correspond respectively to the mass-factor and velocity-factor as already described. It is suggested that there is no essential difference between the various classes of explosives, and that the regulation of the mechanical effect to be produced by an explosive may be obtained by a modification in the conditions of application equally well as by a change in the explosive employed. There is no real distinction between explosion and detonation, or between kinetic pressure and shock, and the relations which exist between the walls of a gun and the powder gases within are the same in character as those between the shot and the armour plate. Applying the theory to the construction of guns it is shown that the modern practice of putting an initial strain upon the walls of a gun by hooping or wire-winding is correct, as although the gun is made weaker to resist pressure and can be torn asunder by less force than before, the weaker system is better adapted to withstand internal impact. The molecules of the inner rings are squeezed closer together, the range of movement within cohesion limits is increased, and the time occupied in developing danger-tension is lengthened. At the same time the range of movement between the molecules of the inner and outer rings is reduced, and the time required for transmitting the pressure from within to without is shortened. The enemy is further away and the ally nearer.

The protection thus afforded ceases to exist if the unstable equilibrium of the gun molecules should become changed into a condition of stable equilibrium, and as the tendency of all molecular structures is towards stable equilibrium, any sudden change of internal stress or any opportunities of movement are availed of to alter the position of the molecules from an abnormal arrangement.

This is suggested as the explanation of the comparatively short lives of built-up guns. At the outset the walls are in a more or less perfect condition of internal stress, but each shot fired disarranges the molecules, which never resume their exact antecedent condition. After a certain number of shocks stable

equilibrium supervenes, and the gun no longer has the power of giving the required support to the innermost ring.

The Author describes a method of testing explosives employed by him, which is as follows:—A segment of a sphere of lead is suspended in the air with the convex side uppermost. To the flat base is attached a charge of the explosive to be tested contained in a cylindrical cartridge case of paraffined paper, the lead and the cartridge being thus in the form of a mushroom.

The effect is measured by the amount of indentation produced. The metal is scarred and pitted in such a manner as to show that there is no approach to uniformity of pressure produced by the explosion, the gas molecules appearing to strike the lead like a charge of small shot.

When a cannon ball is driven along the bore of a gun by the impact of a column of gas, the pressure sustained by the walls of the gun is much less than that exerted on the base of the shot. The column of gas must be considered as a stream of minute projectiles darting onwards with a common movement of translation, and not darting in every direction as in a vessel filled with gas. For utilizing high explosives in firearms and ordnance the Author constructs cartridges lined with soft wood. The lining protects the metal of the gun against a disintegrating shock, and by its resilience enables the gaseous molecules to retain their energy in the form of motion, and to gradually join the onflowing current along the bore of the gun.

The Author gives Tables of the comparative strength of different explosive compounds, his method being to first determine how much heat is set free by the rearrangement of the molecules after deduction of the heat absorbed in breaking up the explosive to start with, obtaining in this way a measure of the total mechanical force rendered available. He then considers the mode in which the explosive develops its strength—whether by a large volume of gas at comparatively low temperature or by a small volume highly heated, and is then in a position to discriminate as to the particular use for which any explosive is adapted. There follows a description of the composition and method of manufacture of a number of so-called smokeless powders, and among them Emmensite and Gelbrite, invented and manufactured by himself, together with an account of experiments made upon them in the United States. The article concludes with an account of tests made with different alloys of aluminium bronze, with a view of ascertaining the behaviour of the material under conditions of sudden stress.

There are numerous photographs.

S. W. B.

Air-Moistening in Spinning- and Weaving-Mills.

By F. DESQUIENS.

(Le Génie Civil, vol. xx., 1892, p. 275.)

The favourable influence of damp air in the operations of spinning and weaving is generally recognized, and various methods for moistening the air artificially have been advocated. The one here described is that invented by Körting Brothers, of Paris.

The essential part of the apparatus is a spiral tuyere, which impresses on a jet of water forced through it a rotary movement that causes it to emerge in the form of an inverted cone, and divided into fine spray. This cone of water carries with it a great part of the surrounding air, an effect which is increased by the form of the casing, which presents a series of cones increasing in diameter one above the other. A sieve and a set of louvre blades facing the jet separate all the drops of water, so that nothing but saturated air passes into the room. A small pump delivers the water at 85 lbs. pressure, and pulverizes 22 gallons per hour in each apparatus, of which about 21 gallons is returned to a tank to be filtered and repumped.

The apparatus can be regulated by an admission-valve that varies the pressure, or by varying the angle of the louvre blades. As there are no moving parts the apparatus costs little to maintain, and lasts indefinitely, while it is very cheap in first cost compared with the work it does. The article is illustrated by one engraving.

C. F. F.

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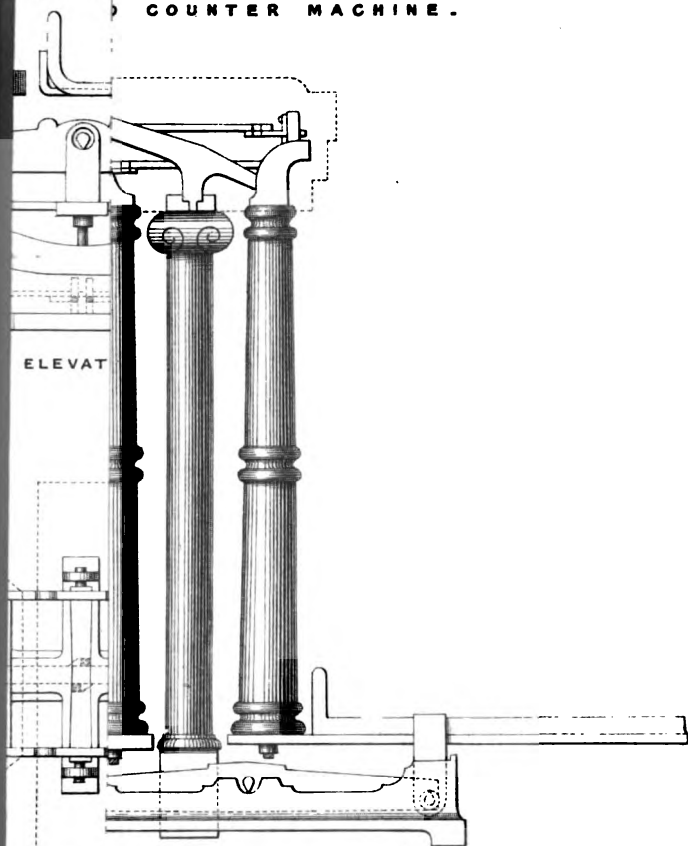
Fig

Fig.^s 9.

PLATE 1.

G CO

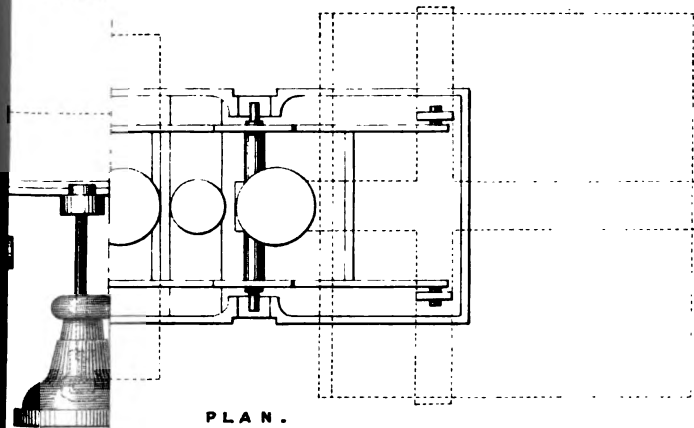
COUNTER MACHINE.



ELEVAT

ELEVATION.

PLA



PLAN.

Scale : $\frac{1}{8}$ in.

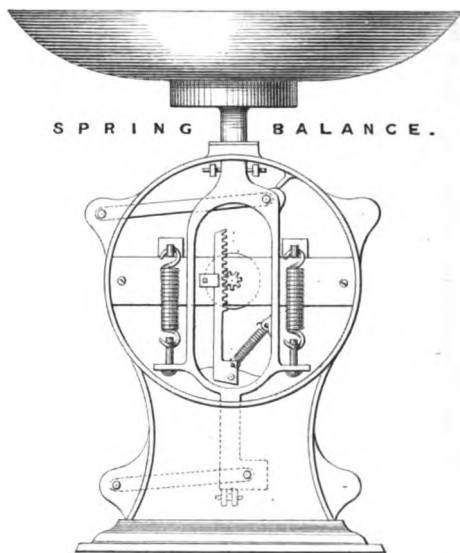
ND ELEVAT

Scale :

TRO^s KELL. & SON, LITH 40, KING ST COVENT GARDEN

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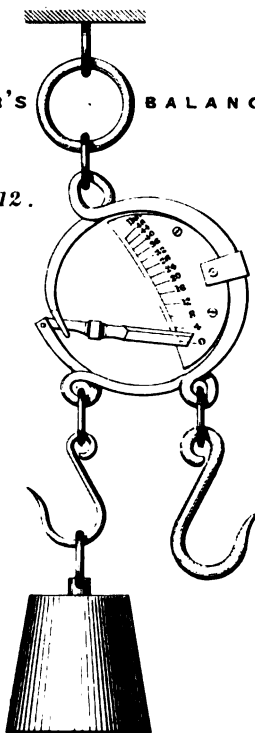
Fig: 11.



Scale: $\frac{1}{4}^{th}$.

MANCUR'S BALANCE.

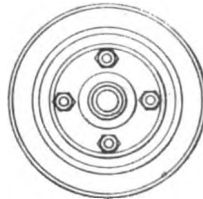
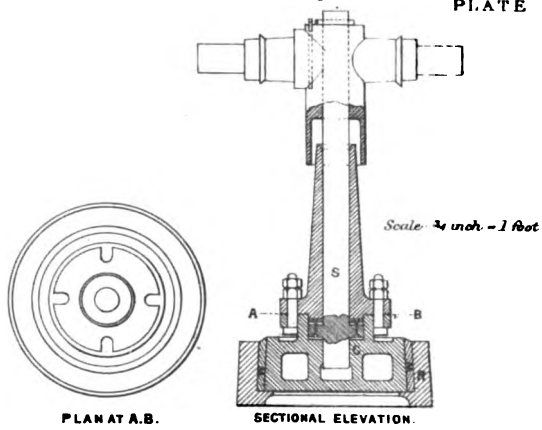
Fig: 12.



Scale: $\frac{1}{4}^{th}$.

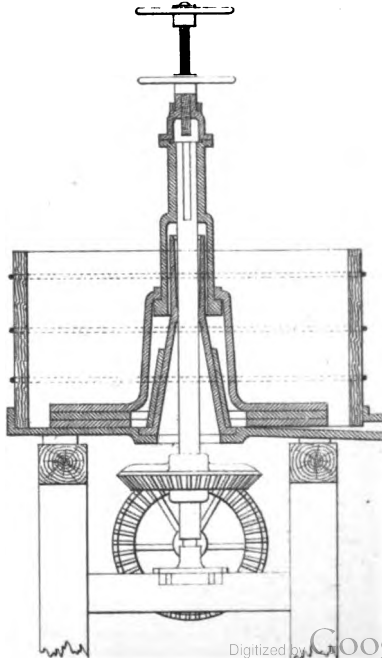
Figs: 21.

PLATE 3.



PAXMAN'S IMPROVED ROLLER HEAD & YOKE.

Fig: 22.



HOUSE

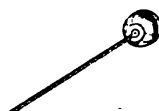
PLATE. 4.

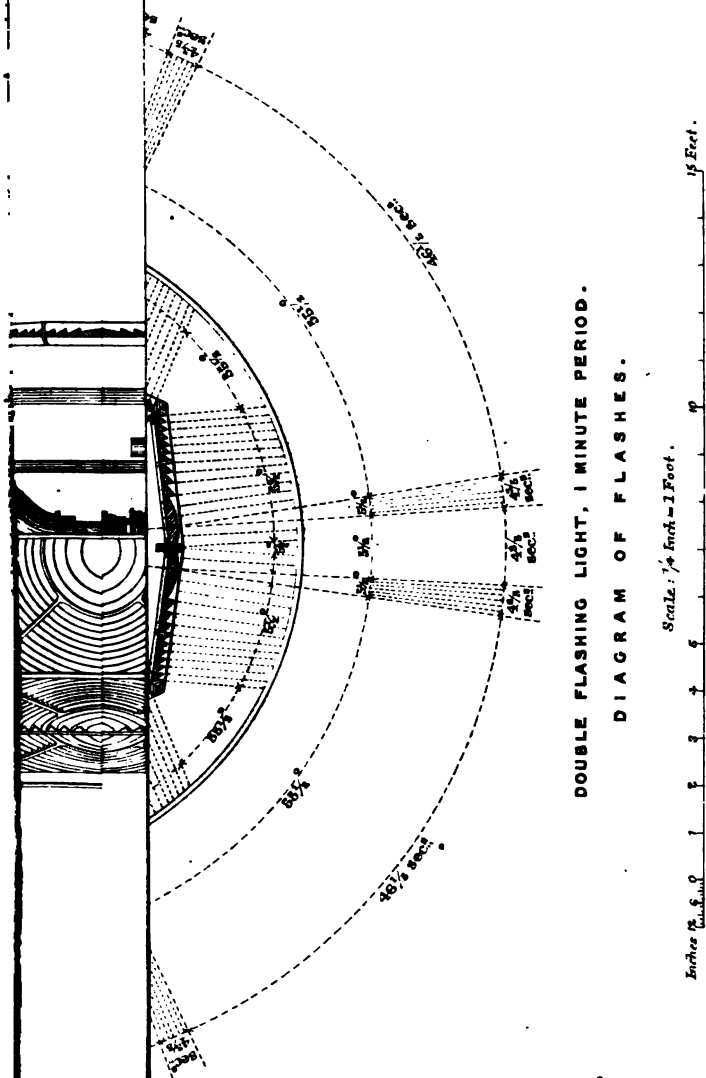
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PLATE 5.

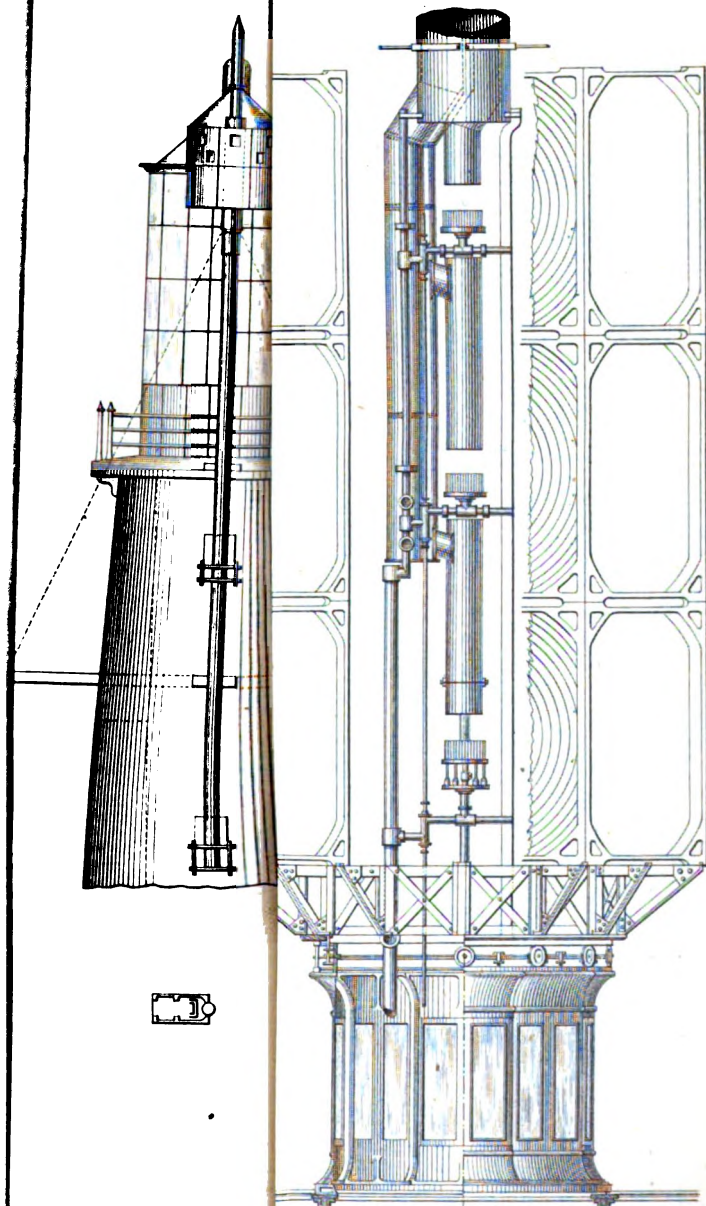
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Fig: 5.





THOS KELL & SON, LITH 40, KING ST OVENT GARDEN



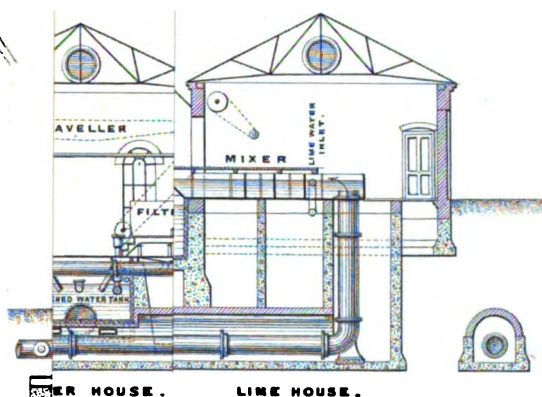
ORY LIGHT.

SECTIONAL ELEVATION.

Scale $\frac{1}{16}$ Inch = 1 Foot.

1 2 3 4 5 6 Feet.

Fig : 2 .

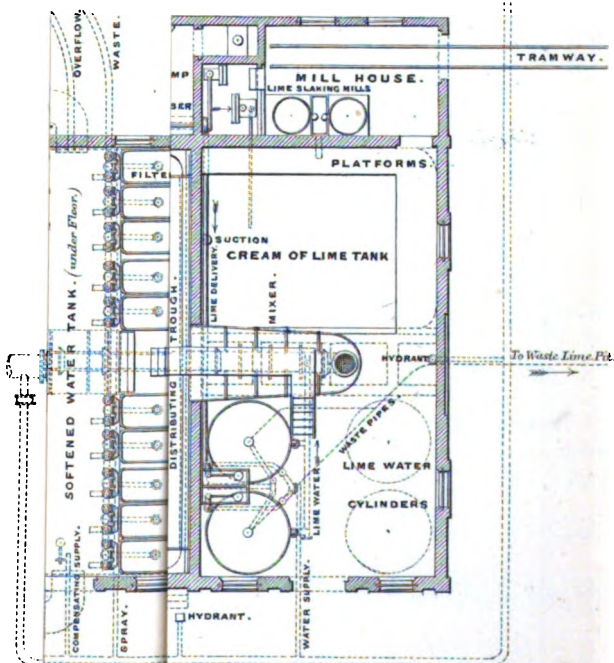


ER HOUSE .

LINE HOUSE .

TION OF :

Fig : 3 .



FTENING

2 & 3 - 20 Feet -

50

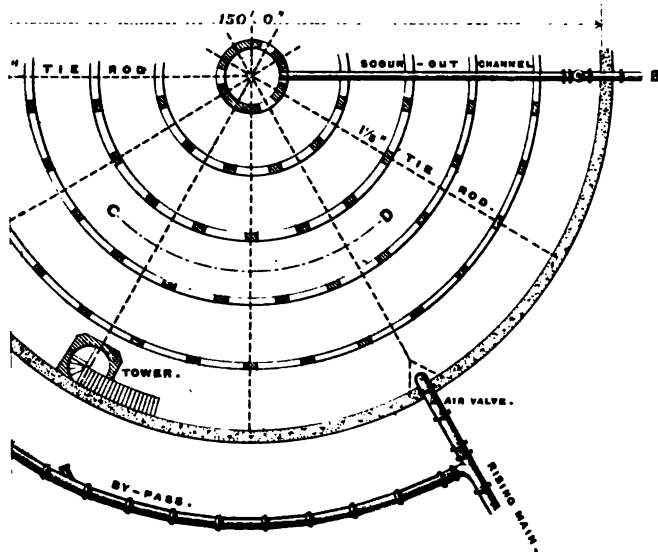
t II .

Fig: 8.



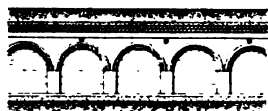
SECTION ON A.B.

Fig: 9.



PLAN.

Fig: 10.



SECTION ON C.D.

OTTERBOURNE RESERVOIR.

Scale for Figs 8, 9 & 10. 40 Feet = 1 Inch.

80 40 20 100 200 Feet.

Fig: 12.

PIVOT, CROSSHEAD AND BOLTS.
CROSSHEAD.

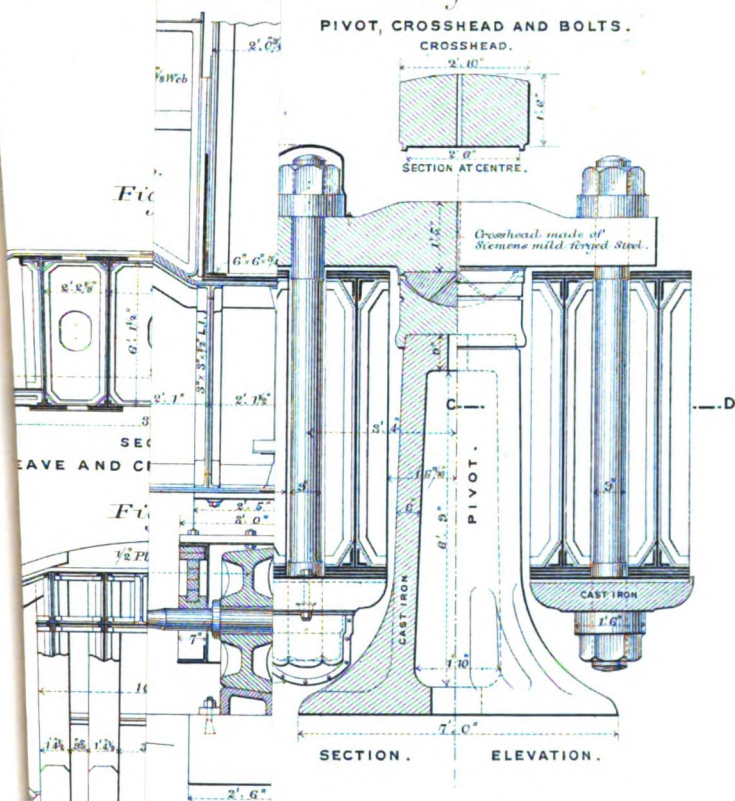
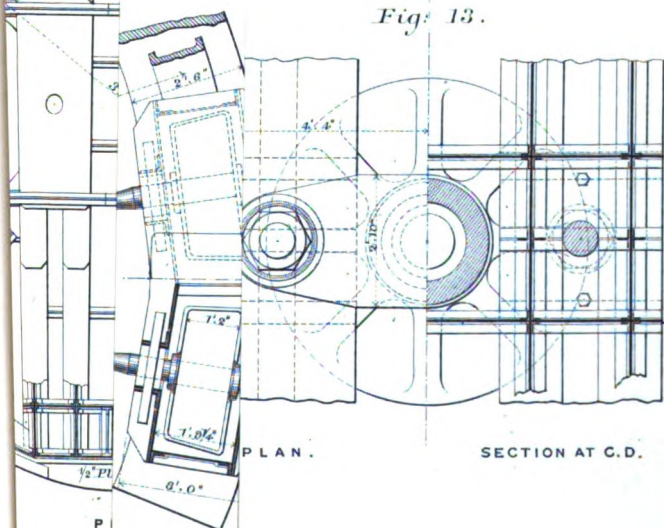
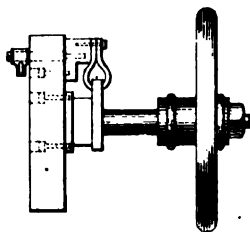
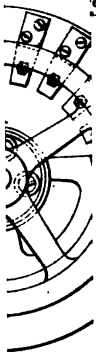


Fig: 13.



gs: 16.



High Pressure
Service Mains

1/4" Full Size. —

overing
valve.

LATING
VERTER.

3 m
15 m

for Heating test.

for Frager Meters.

for Ferranti mercury Meters.

for Ferranti Wright Meters.

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100.

Conductivity
0.1 mho.

Conductivity
1 mho.



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